TRAITE DE COOPERATION EN MATIERE DE BREVETS

Expéditeur: le BUREAU INTERNATIONAL

PCT

NOTIFICATION DE L'ENREGISTREMENT D'UN CHANGEMENT

(règle 92bis.1 et instruction administrative 422 du PCT)

Destinataire:

VIDON, Patrice
Cabinet Patrice Vidon
Immeuble Germanium
80, avenue des Buttes de Coësmes
F-35700 Rennes
FRANCE

Date d'expédition (jour/mois/année) 20 juillet 1999 (20.07.99)	
Référence du dossier du déposant ou du mandataire 4246.WO	**NOTIFICATION IMPORTANTE**
Demande internationale no PCT/FR98/01398	**Date du dépôt international** (jour/mois/année) 30 juin 1998 (30.06.98)

1. Les renseignements suivants étaient enregistrés en ce qui concerne:

☒ le déposant ☒ l'inventeur ☐ le mandataire ☐ le représentant commun

Nom et adresse	Nationalité (nom de l'Etat)	Domicile (nom de l'Etat)
COMBELLES, Pierre 22, rue de la Godmendière F-35000 Rennes FRANCE	FR	FR
	no de téléphone	
	no de télécopieur	
	no de téléimprimeur	

2. Le Bureau international notifie au déposant que le changement indiqué ci-après a été enregistré en ce qui concerne:

☐ la personne ☐ le nom ☒ l'adresse ☐ la nationalité ☐ le domicile

Nom et adresse	Nationalité (nom de l'Etat)	Domicile (nom de l'Etat)
COMBELLES, Pierre 32, rue Bigot de Préameneu F-35000 Rennes FRANCE	FR	FR
	no de téléphone	
	no de télécopieur	
	no de téléimprimeur	

3. Observations complémentaires, le cas échéant:

4. Une copie de cette notification a été envoyée:

☒ à l'office récepteur
☐ à l'administration chargée de la recherche internationale
☒ à l'administration chargée de l'examen préliminaire international
☐ aux offices désignés concernés
☒ aux offices élus concernés
☐ autre destinataire:

Bureau international de l'OMPI **34, chemin des Colombettes** **1211 Genève 20, Suisse**	Fonctionnaire autorisé: Kari Huynh-Khuong
no de télécopieur (41-22) 740.14.35	no de téléphone (41-22) 338.83.38

Formulaire PCT/IB/306 (mars 1994) 002741669

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TRAITE DE COOPERATION EN MATIERE DE BREVETS

Expéditeur: le BUREAU INTERNATIONAL

PCT

NOTIFICATION D'ELECTION

(règle 61.2 du PCT)

Destinataire:

United States Patent and Trademark Office
(Box PCT)
Crystal Plaza 2
Washington, DC 20231
ÉTATS-UNIS D'AMÉRIQUE

en sa qualité d'office élu

Date d'expédition (jour/mois/année) 09 février 1999 (09.02.99)	
Demande internationale no PCT/FR98/01398	**Référence du dossier du déposant ou du mandataire** 4246.WO
Date du dépôt international (jour/mois/année) 30 juin 1998 (30.06.98)	**Date de priorité** (jour/mois/année) 01 juillet 1997 (01.07.97)
Déposant COMBELLES, Pierre etc	

1. L'office désigné est avisé de son élection qui a été faite:

   [X] dans la demande d'examen préliminaire international présentée à l'administration chargée de l'examen préliminaire international le:

   08 janvier 1999 (08.01.99)

   [ ] dans une déclaration visant une élection ultérieure déposée auprès du Bureau international le:

2. L'élection [X] a été faite

   [ ] n'a pas été faite

   avant l'expiration d'un délai de 19 mois à compter de la date de priorité ou, lorsque la règle 32 s'applique, dans le délai visé à la règle 32.2b).

Bureau international de l'OMPI **34, chemin des Colombettes** **1211 Genève 20, Suisse** no de télécopieur: (41-22) 740.14.35	Fonctionnaire autorisé Jean-Marie McAdams no de téléphone: (41-22) 338.83.38

TRAITE DE COOPERATION EN MATIERE DE BREVETS

PCT

RAPPORT DE RECHERCHE INTERNATIONALE

(article 18 et règles 43 et 44 du PCT)

Référence du dossier du déposant ou du mandataire 4246.WO	**POUR SUITE A DONNER** voir la notification de transmission du rapport de recherche internationale (formulaire PCT/ISA/220) et, le cas échéant, le point 5 ci-après	
Demande internationale n° PCT/FR 98/01398	Date du dépôt international *(jour/mois/année)* 30/06/1998	(Date de priorité (la plus ancienne) *(jour/mois/année)* 01/07/1997
Déposant FRANCE TELECOM et al.		

Le présent rapport de recherche internationale, établi par l'administration chargée de la recherche internationale, est transmis au déposant conformément à l'article 18. Une copie en est transmise au Bureau international.

Ce rapport de recherche internationale comprend 3 feuilles.

[X] Il est aussi accompagné d'une copie de chaque document relatif à l'état de la technique qui y est cité.

1. [ ] **Il a été estimé que certaines revendications ne pouvaient pas faire l'objet d'une recherche** (voir le cadre I).

2. [ ] **Il y a absence d'unité de l'invention** (voir le cadre II).

3. [ ] La demande internationale contient la divulgation **d'un listage de séquence de nucléotides ou d'acides aminés** et la recherche internationale a été effectuée sur la base du listage de séquence
   - [ ] deposé avec la demande internationale
   - [ ] fourni par le déposant séparément de la demande internationale
     - [ ] sans être accompagnée d'une déclaration selon laquelle il n'inclut pas d'éléments allant au-delà de la divulgation faite dans la demande internationale telle qu'elle a été déposée.
   - [ ] transcrit par l'administration

4. En ce qui concerne le titre,
   - [ ] le texte est approuvé tel qu'il a été remise par le déposant.
   - [X] Le texte a été établi par l'administration et a la teneur suivante:

   MODULATION MULTIPORTEUSE EMPLOYANT DES FONCTIONS PROTOTYPES PONDEREES

5. En ce qui concerne **l'abrégé**,
   - [X] le texte est approuvé tel qu'il a été remis par le déposant
   - [ ] le texte (reproduit dans le cadre III) a été établi par l'administration conformément à la règle 38.2b). Le déposant peut présenter des observations à l'administration dans un délai d'un mois à compter de la date d'expédition du présent rapport de recherche internationale.

6. La figure **des dessins** à publier avec l'abrégé est la suivante:

   Figure n° 2
   - [ ] suggérée par le déposant.
   - [ ] parce que le déposant n'a pas suggéré de figure.
   - [X] parce que cette figure caractérise mieux l'invention.

   [ ] Aucune des figures n'est à publier.

RAPPORT DE RECHERCHE INTERNATIONALE

Demande Internationale No
PCT/FR 98/01398

A. CLASSEMENT DE L'OBJET DE LA DEMANDE
CIB 6 H04L27/26

Selon la classification internationale des brevets (CIB) ou à la fois selon la classification nationale et la CIB

B. DOMAINES SUR LESQUELS LA RECHERCHE A PORTE

Documentation minimale consultée (système de classification suivi des symboles de classement)
CIB 6 H04L

Documentation consultée autre que la documentation minimale dans la mesure où ces documents relèvent des domaines sur lesquels a porté la recherche

Base de données électronique consultée au cours de la recherche internationale (nom de la base de données, et si cela est réalisable, termes de recherche utilisés)

C. DOCUMENTS CONSIDERES COMME PERTINENTS

Catégorie °	Identification des documents cités, avec, le cas échéant, l'indication des passages pertinents	no. des revendications visées
A	DANESFAHANI ET AL.: "Multirate extensions to COSSAP and lessons learnt from developing advanced models" IEE COLLOQUIUM ON COMMUNICATIONS SIMULATION AND MODELLING TECHNIQUES, no. 139, 28 septembre 1993, pages 7/1-7/6, XP000577280 voir page 2, colonne de droite, alinéa 4 - page 3, colonne de gauche, alinéa 2 ---	1-19
A	CROCHIERE & RABINER: "Multirate Digital Signal Processing" 1983 , PRENTICE-HALL , ENGLEWOOD CLIFFS, US XP002059943 voir page 313, alinéa 7.2.5 - page 325, alinéa 7.2.7 ---	1-19
	-/--	

[X] Voir la suite du cadre C pour la fin de la liste des documents

[X] Les documents de familles de brevets sont indiqués en annexe

° Catégories spéciales de documents cités:

"A" document définissant l'état général de la technique, non considéré comme particulièrement pertinent

"E" document antérieur, mais publié à la date de dépôt international ou après cette date

"L" document pouvant jeter un doute sur une revendcation de priorité ou cité pour déterminer la date de publication d'une autre citation ou pour une raison spéciale (telle qu'indiquée)

"O" document se référant à une divulgation orale, à un usage, à une exposition ou tous autres moyens

"P" document publié avant la date de dépôt international, mais postérieurement à la date de priorité revendiquée

"T" document ultérieur publié après la date de dépôt international ou la date de priorité et n'appartenenant pas à l'état de la technique pertinent, mais cité pour comprendre le principe ou la théorie constituant la base de l'invention

"X" document particulièrement pertinent; l'invention revendiquée ne peut être considérée comme nouvelle ou comme impliquant une activité inventive par rapport au document considéré isolément

"Y" document particulièrement pertinent; l'invention revendiquée ne peut être considérée comme impliquant une activité inventive lorsque le document est associé à un ou plusieurs autres documents de même nature, cette combinaison étant évidente pour une personne du métier

"&" document qui fait partie de la même famille de brevets

Date à laquelle la recherche internationale a été effectivement achevée	Date d'expédition du présent rapport de recherche internationale
21 octobre 1998	28/10/1998

Nom et adresse postale de l'administration chargée de la recherche internationale	Fonctionnaire autorisé
Office Européen des Brevets, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Scriven, P

1

Formulaire PCT/ISA/210 (deuxième feuille) (juillet 1992)

Demande Internationale No
PCT/FR 98/01398

C.(suite) DOCUMENTS CONSIDERES COMME PERTINENTS

Catégorie °	Identification des documents cités, avec,le cas échéant, l'indicationdes passages pertinents	no. des revendications visées
A	FLIEGE: "Orthogonal multiple carrier data transmission" EUROPEAN TRANSACTIONS ON TELECOMMUNICATIONS AND RELATED TECHNOLOGIES., vol. 3, no. 3, mai 1992, pages 255-264, XP000304924 MILAN, IT voir page 255, colonne de droite, alinéa 2 - page 256, colonne de droite, alinéa 4 ---	1,9,11, 16,19
A	EP 0 668 679 A (ITALTEL) 23 août 1995 voir colonne 2, ligne 38 - colonne 3, ligne 10 -----	1,9,11, 16,19

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/FR 98/01398

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0668679 A	23-08-1995	IT 1273793 B	10-07-1997

QL

Translation

2

PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference 4246.WO	FOR FURTHER ACTION	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)
International application No. PCT/FR98/01398	International filing date (*day/month/year*) 30 June 1998 (30.06.1998)	Priority date (*day/month/year*) 01 July 1997 (01.07.1997)
International Patent Classification (IPC) or national classification and IPC H04L 27/26		
Applicant FRANCE TELECOM		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

☒ This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

These annexes consist of a total of 7 sheets.

3. This report contains indications relating to the following items:

- I ☒ Basis of the report
- II ☐ Priority
- III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
- IV ☐ Lack of unity of invention
- V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
- VI ☐ Certain documents cited
- VII ☐ Certain defects in the international application
- VIII ☐ Certain observations on the international application

Date of submission of the demand	Date of completion of this report
08 January 1999 (08.01.1999)	15 October 1999 (15.10.1999)
Name and mailing address of the IPEA/EP European Patent Office D-80298 Munich, Germany Facsimile No. 49-89-2399-4465	Authorized officer Telephone No. 49-89-2399-0

Form PCT/IPEA/409 (cover sheet) (January 1994)

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/FR98/01398

I. Basis of the report

1. This report has been drawn on the basis of (*Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to the report since they do not contain amendments.*):

☐ the international application as originally filed.

☒ the description, pages 1-4, 6-26, as originally filed,
pages ______, filed with the demand,
pages 5, filed with the letter of 27 September 1999 (27.09.1999),
pages ______, filed with the letter of ______.

☒ the claims, Nos. ______, as originally filed,
Nos. ______, as amended under Article 19,
Nos. ______, filed with the demand,
Nos. 1-18, filed with the letter of 27 September 1999 (27.09.1999),
Nos. ______, filed with the letter of ______.

☒ the drawings, sheets/fig 1/14-14/14, as originally filed,
sheets/fig ______, filed with the demand,
sheets/fig ______, filed with the letter of ______,
sheets/fig ______, filed with the letter of ______.

2. The amendments have resulted in the cancellation of:

☐ the description, pages ______
☐ the claims, Nos. ______
☐ the drawings, sheets/fig ______

3. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).

4. Additional observations, if necessary:

V. **Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement**

1. Statement

Novelty (N)	Claims	1-18	YES
	Claims		NO
Inventive step (IS)	Claims	1-18	YES
	Claims		NO
Industrial applicability (IA)	Claims	1-18	YES
	Claims		NO

2. Citations and explanations

1. The closest prior art and its disadvantages

In the present report reference is made to the following documents:

D1: DANESFAHANI ET AL.: "Multirate extensions to COSSAP and lessons learnt from developing advanced models" IEE COLLOQUIUM ON COMMUNICATIONS SIMULATION AND MODELLING TECHNIQUES, no. 139, 28 September 1993, pages 7/1-7/6, XP000577280

D2: CROCHIERE & RABINER: "Multirate Digital Signal Processing" 1983, PRENTICE-HALL, ENGLEWOOD CLIFFS, US XP002059943

D3: FLIEGE: "Orthogonal multiple carrier data transmission", EUROPEAN TRANSACTIONS ON TELECOMMUNICATIONS AND RELATED TECHNOLOGIES., Vol. 3, no. 3, May 1992, pages 255-264, XP000304924, MILAN, IT

D4: EP-A-0 668 679 (ITALTEL) 23 August 1995

Document D1, which is analysed in the description, concerns the simulation of an SCPC/FDMA signal

demodulator. It does not concern either orthogonal carriers or signals of density 2. For this reason it is preferable not to put the features of D1 in the preamble of Claim 1, which concerns a modulation method. The problem of such a method is that it cannot be used for a large number of channels.

Document D2 is only considered to describe the technical background and concerns the field of weighted overlap and add structures.

Documents D3 and D4 are also considered to be technical background documents in the field of multiphase modulators.

2) The problem and the solution

The problem that the present invention aims to solve can therefore be considered to be that of reducing the number of calculations in the implementation of a method for a large number of channels.

Using the technical features of Claim 1, the solution revolves around an elaborate handling of the indices and an adapting of the input and output which consists of associating 2M coefficients representative of data corresponding to M samples to be transmitted. At demodulation (Claim 11) this is translated by the corresponding processing step of these 2M complex values.

3) Conclusion

The solution of the problem of the prior art, proposed in Claim 1 (modulation method), in Claim 9 (modulation device), in Claim 11 (demodulation

method) and Claim 16 (demodulation device) in the present application, is therefore considered to involve an inventive step (PCT Article 33(3)).

Claims 2-8, 10 and 12-15 and 17-18 are dependent on the independent claims and therefore also fulfil the requirements of the PCT as regards novelty and inventive step.

Claims 1-18 are also industrially applicable.

3T

TRAITE DE COOPERATION EN MATIERE DE BREVETS

REC'D 20 OCT 1999
WIPO PCT

PCT

RAPPORT D'EXAMEN PRELIMINAIRE INTERNATIONAL

(article 36 et règle 70 du PCT)

Référence du dossier du déposant ou du mandataire 4246.WO	**POUR SUITE A DONNER**	voir la notification de transmission du rapport d'examen préliminaire international (formulaire PCT/IPEA/416)
Demande internationale n° PCT/FR98/01398	Date du dépot international *(jour/mois/année)* 30/06/1998	Date de priorité *(jour/mois/année)* 01/07/1997
Classification internationale des brevets (CIB) ou à la fois classification nationale et CIB H04L27/26		
Déposant FRANCE TELECOM et al.		

1. Le présent rapport d'examen préliminaire international, établi par l'administaration chargée de l'examen préliminaire international, est transmis au déposant conformément à l'article 36.

2. Ce RAPPORT comprend 5 feuilles, y compris la présente feuille de couverture.

   ☒ Il est accompagné d'ANNEXES, c'est-à-dire de feuilles de la description, des revendications ou des dessins qui ont été modifiées et qui servent de base au présent rapport ou de feuilles contenant des rectifications faites auprès de l'administration chargée de l'examen préliminaire international (voir la règle 70.16 et l'instruction 607 des Instructions administratives du PCT).

   Ces annexes comprennent 7 feuilles.

3. Le présent rapport contient des indications relatives aux points suivants:

   I ☒ Base du rapport
   II ☐ Priorité
   III ☐ Absence de formulation d'opinion quant à la nouveauté, l'activité inventive et la possibilité d'application industrielle
   IV ☐ Absence d'unité de l'invention
   V ☒ Déclaration motivée selon l'article 35(2) quant à la nouveauté, l'activité inventive et la possibilité d'application industrielle; citations et explications à l'appui de cette déclaration
   VI ☐ Certains documents cités
   VII ☐ Irrégularités dans la demande internationale
   VIII ☐ Observations relatives à la demande internationale

Date de présentation de la demande d'examen préliminaire internationale 08/01/1999	Date d'achèvement du présent rapport 15. 10. 99
Nom et adresse postale de l'administration chargée de l'examen préliminaire international: Office européen des brevets D-80298 Munich Tél. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Fonctionnaire autorisé Huber, O N° de téléphone +49 89 2399 8967

Formulaire PCT/IPEA/409 (feuille de couverture) (janvier 1994)

RAPPORT D'EXAMEN PRELIMINAIRE INTERNATIONAL

Demande internationale n° PCT/FR98/01398

I. Base du rapport

1. Ce rapport a été rédigé sur la base des éléments ci-après (*les feuilles de remplacement qui ont été remises à l'office récepteur en réponse à une invitation faite conformément à l'article 14 sont considérées, dans le présent rapport, comme "initialement déposées" et ne sont pas jointes en annexe au rapport puisqu'elles ne contiennent pas de modifications.*) :

Description, pages:

1-4,6-26	version initiale	
5	reçue(s) avec télécopie du	27/09/1999

Revendications, N°:

1-18	reçue(s) avec télécopie du	27/09/1999

Revendications, pages:

27-32	reçue(s) avec télécopie du	27/09/1999

Dessins, feuilles:

1/14-14/14	version initiale

2. Les modifications ont entrainé l'annulation :

- ☐ de la description, pages :
- ☐ des revendications, n^{os} :
- ☐ des dessins, feuilles :

3. ☐ Le présent rapport a été formulé abstraction faite (de certaines) des modifications, qui ont été considérées comme allant au-delà de l'exposé de l'invention tel qu'il a été déposé, comme il est indiqué ci-après (règle 70.2(c)) :

4. Observations complémentaires, le cas échéant :

V. Déclaration motivée selon l'article 35(2) quant à la nouveauté, l'activité inventive et la possibilité d'application industrielle; citations et explications à l'appui de cette déclaration

1. Déclaration

Nouveauté	Oui :	Revendications	1-18
	Non :	Revendications	
Activité inventive	Oui :	Revendications	1-18
	Non :	Revendications	
Possibilité d'application industrielle	Oui :	Revendications	1-18
	Non :	Revendications	

2. Citations et explications

voir feuille séparée

Concernant le point V

Déclaration motivée selon l'article 35(2) quant à la nouveauté, l'activité inventive et la possibilité d'application industrielle; citations et explications à l'appui de cette déclaration

1) L'état de la technique le plus proche et ses désavantages

Le présent rapport fait mention des documents suivants cités dans le rapport de recherche.

D1: DANESFAHANI ET AL.: 'Multirate extensions to COSSAP and lessons learnt from developing advanced models' IEE COLLOQUIUM ON COMMUNICATIONS SIMULATION AND MODELLING TECHNIQUES, no. 139, 28 septembre 1993, pages 7/1-7/6, XP000577280

D2: CROCHIERE & RABINER: 'Multirate Digital Signal Processing' 1983 , PRENTICE-HALL , ENGLEWOOD CLIFFS, US XP002059943

D3: FLIEGE: 'Orthogonal multiple carrier data transmission' EUROPEAN TRANSACTIONS ON TELECOMMUNICATIONS AND RELATED TECHNOLOGIES., vol. 3, no. 3, mai 1992, pages 255-264, XP000304924 MILAN, IT

D4: EP-A-0 668 679 (ITALTEL) 23 août 1995

Le document D1, qui est analysé dans la description concerne la simulation d'un démodulateur de signaux SCPC/FDMA. Il ne s'agit ni de signaux à porteuses orthogonales, ni de signaux de densité 2. Pour cette raison est préférable de ne pas mettre les caractéristiques de D1 dans la préambule de la Revendication 1, qui concerne un procédé de modulation. Le défaut d'un tel procédé réside dans le fait qu'il n'est pas utilisable pour un nombre élevé de canaux.

Le document D2 est seulement considéré comme décrivant l'arrière plan technologique et concerne le domaine des structures additives et recouvrement avec des poids (weighted overlap and add structures).

Les documents D3 et D4 sont également considérés comme arrières plans technologique, dans le domaine des modulateurs polyphases.

2) Le problème et la solution

Le problème que se propose de résoudre la présente invention peut donc être vu dans la réduction du nombre de calculs dans la mise en oeuvre d'un procédé pour un nombre de canaux élevés.

A l'aide des caractéristiques techniques de la Revendication 1, la solution repose sur un maniement minutieu des indices et une adaptation des entrées et des sorties, qui consiste à associer 2M coefficients représentatifs des données correspondant à M échantillons à émettre. A la démodulation (Revendication 11), cela se traduit par l'étape correspondante de traitement de ces 2M valeurs complexes.

3) Conclusion

La solution du problème de l'état de la technique, proposée dans la Revendication 1 (procédé de modulation), dans la Revendication 9 (dispositif de modulation), dans la Revendication 11 (procédé de démodulation) et dans la Revendication 16 (dispositif de démodulation) de la présente demande, est donc considérée comme impliquant une activité inventive (Article 33(3) PCT).

Les Revendications 2-8, 10 et 12-15 et 17-18 dépendent des revendication indépendantes et satisfont donc également, en tant que telles, aux conditions requises par le PCT en ce qui concerne la nouveauté et l'activité inventive.

Les Revendications 1-18 sont également applicables industriellement.

< Le document "Multirate extensions to COSSAP and lessons learnt from developing advanced models" (Donesfahani et al - IEEE Colloquium on communications simulation and modelling techniques, n° 139, 28/09/93, pp. 7/1 - 7/6) montre, pour la démodulation de signaux d'un autre type (SCPC/FDMA), une structure dite "weighted overlap-add analyser". Cependant, cette technique est uniquement destinée à la démodulation d'un type particulier de signal, non orthogonal, et s'avère non recommandé, car exigeant un nombre élevé de calculs, dès qu'un nombre important de canaux est prévus.>

(Télévision Numérique). Le "mapping" des bits issus du codeur correcteur d'erreur sera ainsi de type QAM.

Pour une modulation OFDM/QAM, les parties réelle et imaginaire d'un complexe issu de la constellation QAM sont transmises simultanément, tous les temps symbole T_s.

Dans le cas d'une modulation de type OFDM/OQAM, elles sont transmises avec un décalage temporel (Offset QAM) d'un demi temps symbole ($T_s/2$). Pour une même bande de transmission et un même nombre de sous-porteuses, il faudra donc, pour transmettre un même débit, que le rythme d'émission de symboles multiporteuses de type OFDM/OQAM soit deux fois plus rapide que celui de symboles multiporteuses de type OFDM/QAM.

Ces deux modes de transmission de l'information sont caractérisés par la densité du réseau temps-fréquence $d = 1/(\nu_0 \tau_0)$. Les modulations multiporteuses de type OFDM/OQAM correspondent à une densité $d = 2$, celles de type OFDM/QAM correspondent à une densité $d = 1$.

On peut donc noter qu'une modulation multiporteuse est caractérisée par:

- la densité du réseau "temps-fréquence" sur lequel elle est définie,
- la fonction prototype.

La mise en oeuvre d'une modulation OFDM/OQAM de densité 2, et de la démodulation correspondante, demande une puissance de calcul importante, et une grande capacité de mémorisation. Cela sous-entend donc que les appareils correspondants seront relativement complexes et coûteux. <>

3 - Objectifs de l'invention

L'invention a notamment pour objectif de pallier, ou réduire, ces inconvénients.

Plus précisément, un objectif de l'invention est de fournir des techniques de modulation et de démodulation de signaux multiporteuses qui soient simples et peu coûteuses à mettre en oeuvre, par rapport aux approches directes.

En d'autres termes, l'invention a pour objectif de fournir de telles techniques de modulation et de démodulation, qui limitent le nombre d'opérations à effectuer et la capacité de mémorisation nécessaire.

REVENDICATIONS

1. Procédé de modulation d'un signal multiporteuse de densité $1/(\nu_0.\tau_0)=2$, formé de symboles successifs, comprenant chacun M échantillons à émettre, et constitués d'un jeu de 2M fréquences porteuses orthogonales au sens réel,

l'écart entre deux fréquences porteuses voisines valant ν_0 et l'écart entre les instants d'émission de deux symboles consécutifs, ou temps symbole, valant τ_0,

chacune desdites fréquences porteuses étant modulée selon une même fonction prototype de modulation g(t) présentant une longueur de troncature de $2L\tau_0$,

caractérisé en ce qu'il comprend, à chaque temps symbole, les étapes suivantes :

- obtention d'un jeu de 2M coefficients complexes représentatifs de données à émettre ;
- calcul de 2LM combinaisons linéaires à partir desdits 2M coefficients complexes obtenus, les coefficients de pondération utilisés dans cesdites combinaisons étant représentatifs de ladite fonction prototype g(t),

de façon à obtenir 2LM coefficients ;

- sommation desdits 2LM coefficients pondérés dans des emplacements mémoire prédéterminés respectifs d'une mémoire comprenant 2LM emplacements mémoire représentant 2L groupes de M sommes partielles distinctes,

de façon à former progressivement, dans lesdits emplacements mémoire, sur une durée de $2L\tau_0$, M échantillons à émettre ;

- émission desdits échantillons à émettre.

2. Procédé de modulation selon la revendication 1, caractérisé en ce qu'un échantillon à émettre à l'instant $j\tau_0 + k\tau_0/M$, noté s_{k+jM} s'écrit :

$$s_{k+jM} = \sum_{q=0}^{2L-1} \left[\alpha_{k,q} C_{k,j-q} + \beta_{k,q} C_{k+M,j-q}\right]$$

où : $C_{0,j}$ à $C_{2M-1,j}$ sont les 2M coefficients complexes générés entre les instants $j\tau_0$ et $(j+1)\tau_0$;

$\alpha_{k,q}$ et $\beta_{k,q}$ sont lesdits coefficients de pondération.

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3. Procédé de modulation selon la revendication 2, caractérisé en ce que :

- $\alpha_{k,q} = 0$ pour q impair ;
- $\beta_{k,q} = 0$ pour q pair.

4. Procédé de modulation selon la revendication 3, caractérisé en ce qu'il comprend, pour la génération d'un symbole d'indice j formé de M échantillons, les étapes suivantes :

- obtention de 2M entrées réelles $a_{m,n}$ représentatives d'un signal source ;
-pré-modulation de chacune desdites entrées réelles, produisant 2M coefficients complexes ;
-transformation de Fourier inverse desdits 2M coefficients complexes, produisant 2M coefficients transformés complexes $C_{0,j}$ à $C_{2M-1,j}$;
- pour chacun des M couples ($C_{k,j}$, $C_{(k+M),j}$) dedits coefficients transformés, calcul de 2L couples pondérés, les coefficients de pondération étant représentatives de ladite fonction prototype;
- addition du résultat de chacune desdites 2LM valeurs pondérées au contenu de 2LM zones mémoire distinctes, de façon à construire progressivement les échantillons à émettre constituants les symboles j, (j+1), (j+2),... (j+2L-1);
- émission de M échantillons correspondant aux M plus anciens contenus desdites zones mémoire puis mise à zéro du contenu de cesdites M zones mémoire.

5. Procédé de modulation selon l'une quelconques des revendications 1 à 4, caractérisé en ce que lesdites étapes sont mises en oeuvre au rythme τ_0/M des échantillons.

6. Procédé de modulation selon l'une quelconque des revendications 1 à 5, caractérisé en ce que ladite étape d'émission est suivie d'une étape de mise à jour desdits emplacements mémoire, comprenant :

- un décalage physique du contenu de chacun desdits emplacements mémoire, si ces derniers sont des éléments d'un registre à décalage ; ou
- une mise à jour des adresses d'écriture et de lecture desdits emplacements mémoire, si ces derniers sont des éléments d'une mémoire RAM.

7. Procédé de modulation selon l'une quelconque des revendications 1 à 6,

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caractérisé en ce que lesdits coefficients représentatifs de données à émettre sont obtenus par la mise en oeuvre d'une transformation mathématique comprenant les étapes suivantes:

- application d'une transformation de Fourier inverse réelle ;
- permutation circulaire du résultat de cette transformée inverse de M/2 coefficients vers la gauche;
- multiplication par i^n de chacun desdits coefficients

8. Procédé de modulation selon l'une quelconque des revendications 1 à 7, caractérisé en ce que le signal centré autour de la fréquence $M\nu_0$ s'écrit :

$$s(t) = \sum_n \sum_{m=0}^{2M-1} a_{m,n} (-1)^{m(n+L)} i^{m+n} e^{2i\pi m \nu_0 t} g(t - n\tau_0)$$

9. Dispositif de modulation d'un signal multiporteuse de densité $1/(\nu_0 . \tau_0) = 2$, formé de symboles successifs, comprenant chacun M échantillons à émettre, et constitués d'un jeu de 2M fréquences porteuses orthogonales au sens réel, l'écart entre deux fréquences porteuses voisines valant ν_0 et l'écart entre les instants d'émission de deux symboles consécutifs valant τ_0,

chacune desdites fréquences porteuses étant modulée selon une même fonction prototype de modulation g(t) présentant une longueur de troncature de $2L\tau_0$,

caractérisé en ce qu'il comprend :

- des moyens de mémorisation temporaire de 2L groupes de M sommes partielles ;
- des moyens de pondération de 2M coefficients complexes représentatifs de données à émettre par des coefficients de pondération représentatifs de ladite fonction prototype g(t) ;
- des moyens de sommation des coefficients pondérés dans des emplacements mémoire prédéterminés respectifs desdits moyens de mémorisation temporaire,

de façon à former progressivement, sur une durée de $2L\tau_0$, lesdits échantillons à émettre.

10. Dispositif de modulation selon la revendication 9, caractérisé en ce qu'il comprend :

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- des moyens de transformation mathématique délivrant lesdits coefficients représentatifs de données à émettre au rythme $\tau_0/2M$ et dans l'ordre suivant $(C_{0,j}, C_{M+1,j}),\ldots(C_{M-1,j}, C_{2M-1,j})$;
- 2LM-M emplacements mémoire de type RAM à écriture et lecture simultanées ;
- N multiplieurs complexes fonctionnant au rythme $N\tau_0/2LM$, N valant 1, 2, 4,...ou 2L.

11. Procédé de démodulation d'un signal reçu, correspondant à un signal émis multiporteuse de densité $1/(\nu_0.\tau_0) = 2$, formé de symboles successifs, représentés chacun par M échantillons à émettre, et constitués d'un jeu de 2M fréquences porteuses orthogonales au sens réel,

l'écart entre deux fréquences porteuses voisines valant ν_0 et l'écart entre les instants d'émission de deux symboles consécutifs, ou temps symbole, valant τ_0, chacune desdites fréquences porteuses étant modulée selon une même fonction prototype de modulation g(t) présentant une longueur de troncature de $2L\tau_0$,

caractérisé en ce que l'on reconstruit une estimation des 2M données réelles émises à un temps symbole donné, à l'aide des étapes suivantes:

- échantillonnage dudit signal reçu à la fréquence d'échantillonnage τ_0/M, délivrant M échantillons complexes reçus ;
- mémorisation de chacun desdits M échantillons complexes reçus dans un emplacement prédéterminé d'une mémoire d'entrée comprenant 2ML emplacements complexes, dans laquelle ont été préalablement mémorisés (2L-1)M échantillons reçus pendant les 2L-1 temps symbole précédents ;
- multiplication des 2ML valeurs contenues dans ladite mémoire d'entrée par des coefficients représentatifs de ladite fonction prototype ;
- repliement temporel, par sommation de 2M séries de L résultats de multiplication, de façon à obtenir 2M valeurs complexes ;
- traitement desdites 2M valeurs complexes pour former lesdites estimations des 2M données réelles émises.

12. Procédé de démodulation selon la revendication 11, caractérisé en ce que les 2M valeurs complexes issues de l'étape de repliement temporel entre les instants

$(j+2L-1)\tau_0$ et $(j+2L)\tau_0$ s'écrivent :

$$R_{k',j} = \sum_{q'=0}^{2L-1} \alpha'_{k,q'} r_{k'+(j+q')M}$$

$$R_{k'+M,j} = \sum_{q'=0}^{2L-1} \beta'_{k,q'} r_{k'+(j+q')M}$$

où : $r_{k'+(j+q')M}$ représente l'échantillon reçu à l'instant $k'\tau_0+(j+q')\tau_0/M$;

$\alpha'_{k,q'}$ et $\beta'_{k,q'}$ sont lesdits coefficients de pondération.

13. Procédé de démodulation selon l'une quelconque des revendications 11 et 12, caractérisé en ce que :

- $\alpha'_{k,q'} = 0$ pour q' impair ;
- $\beta'_{k,q'} = 0$ pour q' pair.

14. Procédé selon l'une quelconque des revendications 11 à 13, caractérisé en ce que ladite étape de traitement comprend les étapes suivantes :

- application d'une transformation mathématique inverse de celle effectuée lors de la modulation sur lesdites 2M valeurs complexes, délivrant 2M valeurs transformées ;
- correction de distorsions de phase et/ou d'amplitude dues au canal de transmission ;
- extraction de la partie réelle desdites valeurs complexes transformées.

15. Procédé de démodulation selon l'une quelconque des revendications 11 à 14, caractérisé en ce que lesdites étapes sont mise en oeuvre au rythme τ_0/M des échantillons.

16. Dispositif de démodulation d'un signal reçu, correspondant à un signal émis multiporteuse de densité $1/(\nu_0.\tau_0) = 2$, formé de symboles successifs, représentés chacun par M échantillons à émettre, et constitués d'un jeu de 2M fréquences porteuses orthogonales au sens réel,

l'écart entre deux fréquences porteuses voisines valant ν_0 et l'écart entre les instants d'émission de deux symboles consécutifs, ou temps symbole, valant τ_0, chacune desdites fréquences porteuses étant modulée selon une même fonction

prototype de modulation présentant une longueur de troncature de $2L\tau_0$,

caractérisé en ce qu'il comprend :

- des moyens d'échantillonnage dudit signal reçu ;
- des moyens de mémorisation temporaire des échantillons complexes échantillonnés, comprenant 2ML emplacements complexes ;
- des moyens de multiplication desdits échantillons mémorisés par des coefficients de pondération représentatifs de ladite fonction prototype ;
- des moyens de repliement temporel, assurant la sommation de L résultats de pondération, de façon à obtenir 2M valeurs complexes ;
- des moyens de traitement desdites valeurs complexes, délivrant une estimation de 2M données réelles émises à chaque temps symbole.

17. Dispositif de démodulation selon la revendication 16, caractérisé en ce que lesdits moyens de traitement comprennent :

- des moyens de transformation mathématique inverse de celle effectuée lors de la modulation sur lesdites 2M valeurs complexes ;
- des moyens de correction de distorsions de phase et/ou d'amplitude dues au canal de transmission ;
- des moyens d'extraction de la partie réelle des valeurs transformées.

18. Dispositif de démodulation selon l'une quelconque des revendications 16 et 17, caractérisé en ce qu'il comprend :

- des moyens de mémorisation comprenant 2ML-M emplacements mémoire complexes de type RAM à écriture et lecture simultanée ;
- N multiplieurs complexes fonctionnant au rythme $N\tau_0/2LM$, où N vaut 1, 2, 4 ... ou 2L ;
- des moyens de transformation mathématique fonctionnant au rythme $\tau_0/2M$, dont les entrées, à l'étape j, $R_{0,j}$ à $R_{2M-1,j}$ sont lues dans l'ordre $(R_{0,j}, R_{M,j})$, $(R_{1,j}, R_{M+1,j})$,... $(R_{M-1,j}, R_{2M-1,j})$.

~~19. Procédé de filtrage délivrant des séries de M valeurs complexes de sortie~~ délivrées à intervalles réguliers, à partir de 2L séries de 2M valeurs complexes d'entrée,

lesdites M valeurs complexes correspondant à une somme pondérée de 2L desdites

Copie à l'intention de l'office élu (EO/EP) PCT/FR98/01398

TRAITE DE COOPERATION EN MATIERE DE BREVETS

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NOTIFICATION DE L'ENREGISTREMENT D'UN CHANGEMENT

(règle 92bis.1 et instruction administrative 422 du PCT)

Expéditeur: le BUREAU INTERNATIONAL

Destinataire:

VIDON, Patrice
Cabinet Patrice Vidon
Immeuble Germanium
80, avenue des Buttes de Coësmes
F-35700 Rennes
FRANCE

Date d'expédition (jour/mois/année) 20 juillet 1999 (20.07.99)	
Référence du dossier du déposant ou du mandataire 4246.WO	**NOTIFICATION IMPORTANTE**
Demande internationale no PCT/FR98/01398	Date du dépôt international (jour/mois/année) 30 juin 1998 (30.06.98)

1. Les renseignements suivants étaient enregistrés en ce qui concerne:

[X] le déposant [X] l'inventeur [ ] le mandataire [ ] le représentant commun

Nom et adresse	Nationalité (nom de l'Etat)	Domicile (nom de l'Etat)
COMBELLES, Pierre 22, rue de la Godmendière F-35000 Rennes FRANCE	FR	FR
	no de téléphone	
	no de télécopieur	
	no de téléimprimeur	

2. Le Bureau international notifie au déposant que le changement indiqué ci-après a été enregistré en ce qui concerne:

[ ] la personne [ ] le nom [X] l'adresse [ ] la nationalité [ ] le domicile

1-CD

Nom et adresse	Nationalité (nom de l'Etat)	Domicile (nom de l'Etat)
COMBELLES, Pierre 32, rue Bigot de Préameneu F-35000 Rennes FRANCE JRX	FR	FR
	no de téléphone	
	no de télécopieur	
	no de téléimprimeur	

3. Observations complémentaires, le cas échéant:

4. Une copie de cette notification a été envoyée:

[X] à l'office récepteur
[ ] à l'administration chargée de la recherche internationale
[X] à l'administration chargée de l'examen préliminaire international
[ ] aux offices désignés concernés
[X] aux offices élus concernés
[ ] autre destinataire:

Bureau international de l'OMPI **34, chemin des Colombettes** **1211 Genève 20, Suisse**	Fonctionnaire autorisé: Kari Huynh-Khuong
no de télécopieur (41-22) 740.14.35	no de téléphone (41-22) 338.83.38

MULTICARRIER MODULATION USING WEIGHTED PROTOTYPE FUNCTIONS

1 - Field of the Invention

1-1 General Points

The field of the invention is that of the transmission or broadcasting of digital data, or of analog and sampled data, designed to be received especially by mobiles. More specifically, the invention relates to the implementation of OFDM/OQAM type multicarrier signals. In other words, the invention applies to density 2 or even higher density signals.

It is known that multicarrier modulation has many useful features, especially when it is associated with error-correcting encoding and interleaving. The COFDM (Coded Orthogonal Frequency Division Multiplexing) technique has also been chosen for the European digital audio broadcasting (DAB) standard and for the terrestrial digital video broadcasting (DVB-T).

The COFDM technique offers a particularly simple system of equalization, namely the use of a guard interval, also called a cyclical prefix. This cyclical prefix provides for robust behaviour in the face of the echoes but at the cost of a relatively major loss of spectral efficiency.

This problem is discussed inter alia in the French patent application No. FR-95 05455 (in which the COFDM modulation is called an OFDM/QAM modulation). To overcome this problem, this patent document presents a new technique for the implementation of OFDM/OQAM type multicarrier modulations.

It will be noted that the different types of modulation discussed hereinafter are designated in a slightly different way in this prior art document and in the present patent application. The following table gives the correspondence :

FR95 05455 :	Present Document:
OFDM/QAM	OFDM/QAM/OFDM
OFDM/OQAM	OFDM/OQAM/NYQUIST

OFDM/OMSK OFDM/OQAM/MSK

OFDM/IOTA OFDM/OQAM/IOTA

The term terme « OQAM » refers to the « Offset Quadratic Amplitude Modulation » definition. This expresses the fact that, for such modulations, there is a temporal offset between the transmission of the in-phase part and that of the in-quadrature part of a QAM symbol.

1-2 Applications

The invention can be applied in very many fields, especially when high spectral efficiency is sought and when the channel is highly non-stationary.

A first category of applications relates to terrestrial digital radio-broadcasting, whether of images, sound and/or data. In particular, the invention can be applied to synchronous broadcasting which intrinsically generates long-term multiple paths. It can also be advantageously applied to broadcasting towards mobile bodies.

Another category of applications relates to digital radiocommunications. The invention can be applied especially in systems of digital communications towards mobiles using high bit rates.

2 - Reminders

2-1 Transmission channel

In a radiomobile environment, the transmitted wave undergoes multiple reflections, and the receiver therefore receives a sum of versions delayed by the transmitted signal. Each of these versions is attenuated and phase-shifted randomly. Since the receiver is assumed to be in motion, the Doppler effect acts also on each path.

The conjunction of these efforts results in a non-stationary channel with deep fading at certain frequencies (frequency selective channel). For the applications referred to here, the transmission band is greater than the coherence band of the channel (the band for which the frequency response to the channel may be considered to be constant on a given duration), and fading thus appears in the band, i.e. at a given point in time, certain frequencies are highly attenuated.

2-2 Description of a multicarrier modulation

A multicarrier modulation is above all a digital modulation, namely a method for the generation of an electromagnetic signal out of the digital information to be transmitted. The originality and value of such a modulation is that it subdivides the limited band allocated to the signal into subbands. In these subbands, which have a chosen width smaller than the coherence band of the channel, the channel may be considered to be constant for a duration of transmission of a symbol, chosen to be smaller than the coherence time of the channel.

The digital information to be transmitted during this period is then distributed over each of these subbands. This has two uses in particular:

- reducing the modulation speed (namely increasing the symbol duration) without modifying the transmitted bit rate,
- simply modelling the action of the channel on each of the subbands: complex multiplier.

It will be noted that, in reception, a system of low complexity for the correction of the data elements received (complex division by the estimated channel) enables a recovery of the information transmitted on each of the carriers satisfactorily except for the carriers that have undergone a deep fading. In this case, if no steps for protecting the information have been taken, the data elements conveyed by these carriers will be lost. A multicarrier system therefore ensures that the generation of the electrical system must be preceded by digital data processing (error corrective encoding and interleaving).

The patent No. FR 95/05455 gives a detailed description of the two types of existing multicarrier modulation. Their characteristics may be briefly recalled here.

2-2-2 Notations

Spacing between two adjacent carriers of the multiplex of carriers: ν_0.

Temporal spacing between two multicarrier symbols transmitted (symbol time): τ_0.

2-2-3 The prototype function

The shaping filter for each of the carriers of the multiplex is the same. It corresponds to the prototype function characterizing the multicarrier modulation.

Let $g(t)$ be this prototype function, the signal transmitted at each instant $n\tau_0$, on the mth central frequency subband ν_m, is $a_{m,n}e^{i\varphi_{m,n}}e^{2i\pi\nu_m t}g(t-nt_0)$.

In baseband, the expression of the signal transmitted, centered on the frequency $M\nu_0$ is therefore:

$$s(t) = \sum_n \sum_{m=0}^{2M-1} a_{m,n}e^{i\varphi_{m,n}}e^{2i\pi m\nu_0 t}g(t-n\tau_0) \qquad (1)$$

The functions $e^{i\varphi_{m,n}}e^{2i\pi m\nu_0 t}g(t-n\tau_0)$ are called time-frequency translated functions of $g(t)$. To retrieve the information transmitted by each of the subcarriers, it is necessary to choose $g(t)$ so that its time-frequency translated functions are separable. To be sure of this, it is laid down that these translated functions should be orthogonal in the sense of a scalar product defined on all the finite energy functions (which is a Hilbert space in the mathematical sense). This space accepts two possible scalar products, namely:

- the complex PS $\langle x|y\rangle = \int_R x(t)y^*(t)dt$
- the real PS $\langle x|y\rangle = \Re e \left[\int_R x(t)y^*(t)dt\right]$

Thus two types of multicarrier modulation are defined:

- complex type, or again OFDM/QAM: the function $g(t)$ chosen guarantees an orthogonality of its translated functions in the complex sense (example: OFDM, also called OFDM/QAM/OFDM). In this case, $\varphi_{m,n} = 0$ and the data elements $a_{m,n}$ are complex,
- real type or again OFDM/OQAM: the function $g(t)$ chosen guarantees an orthogonality of its translated functions in the real sense (examples:

OFDM/OQAM/NYQUIST, OFDM/OQAM/MSK, OFDM/OQAM/IOTA).

In this case, $\varphi_{m,n} = (\pi/2)*(m+n)$ and the data elements $a_{m,n}$ are real.

2-2-4 Density of the "time-frequency" network

Since these modulations are designed for transmission at high bit rates, they will be associated with fairly high spectral efficiency values, in the range of 4 bits/s/Hz (digital television). The mapping of the bits coming from the error correction encoder will thus be of the QAM type.

For an OFDM/QAM modulation, the real and imaginary parts of a complex function derived from the QAM constellation are transmitted simultaneously at every symbol time T_s.

In the case of an OFDM/OQAM type modulation, they are transmitted with a temporal offset (QAM offset) of half a symbol time ($T_s/2$). For one and the same transmission band and one and the same number of subcarriers, it is therefore necessary, for one and the same bit rate to be transmitted, that the rate of transmission of OFDM/OQAM type multicarrier symbols should be twice that of the OFDM/QAM type multicarrier symbols.

These two modes of transmission of information are characterized by the density of the time-frequency network $d = 1/(\nu_0\ \tau_0)$. The OFDM/OQAM type multicarrier modulations the correspond to a density $d = 2$, and those of the OFDM/QAM type correspond to a density of $d = 1$.

It may be noted that a multicarrier modulation is characterized by:

- the density of the "time-frequency" network on which it is defined,
- the prototype function.

The implementation of an OFDM/OQAM modulation with a density 2, and of the corresponding demodulation, requires substantial computation power and high storage capacity. This therefore underlines the fact that the corresponding instruments are relatively complex and costly.

3 – Goals of the invention

The invention is designed especially to overcome or reduce these drawbacks. More specifically, a goal of the invention is to provide techniques for the modulation and demodulation of the multicarrier signals that are simple and cost little to implement as compared with the direct approaches.

In other words, it is a goal of the invention to give modulation and demodulation techniques of this kind that limit the number of operations to be performed and the necessary storage capacity.

4 - Description of the invention

These goals as well as others that shall appear hereinafter are achieved according to the invention by means of a method for the modulation of a multicarrier signal with a density $1/(\nu_0.\tau_0)=2$, formed by successive symbols, each comprising M samples to be transmitted and constituted by a set of 2M orthogonal carrier frequencies in the real sense,

the interval between two neighboring carrier frequencies being equal to ν_0 and the interval between the times of transmission of two consecutive symbols, or the symbol time, being equal to τ_0,

each of said carrier frequencies being modulated according to one and the same modulation prototype function g(t) with a truncation length of $2L\tau_0$,

the method comprising, at each symbol time, the following steps:

- the obtaining of a set of 2M complex coefficients representing data to be transmitted;
- the computing of 2LM linear combinations from said 2M complex coefficients obtained, the weighting coefficients used in these combinations representing said prototype function g(t), so as to obtain 2LM coefficients;
- the summing of said 2LM coefficients weighted in the predetermined storage locations of a memory comprising 2LM storage locations representing 2L groups of M distinct partial sums,

so as to gradually form, in said storage locations, over a duration of $2L\tau_0$, M

samples to bc transmitted;

- the sending of said samples to be transmitted.

Thus, according to the invention, the data elements to be processed are stored after weighting and not before. It is thus possible to reduce the memory capacity needed as well as the number of operations performed. The samples to be transmitted are built gradually in each field of storage.

According to one advantageous embodiment of the invention, a sample to be transmitted at the instant $j\tau_0 + k\tau_0/M$, referenced s_{k+jM} is written as follows:

$$s_{k+jM} = \sum_{q=0}^{2L-1} \left[\alpha_{k,q} C_{k,j-q} + \beta_{k,q} C_{k+M,j-q}\right]$$

where:

$C_{o,j}$ to $C_{2M-1,j}$ are the 2M complex coefficients generated between the instants $j\tau_0$ and $(j+1)\tau_0$;

$\alpha_{k,q}$ and $\beta_{k,q}$ are said weighting coefficients.

In the case of an OFDM/OQAM modulation, we will generally have:

- $\alpha_{k,q} = 0$ for q as an odd parity number;
- $\beta_{k,q} = 0$ for q as an even parity number.

The number of operations performed is therefore further reduced by half.

In a preferred embodiment of the invention, the method comprises, for the generation of a symbol with an index j formed by M samples, the following steps:

- the obtaining of 2M real inputs $a_{m,n}$ representing a source signal;

- the pre-modulation of each of said real inputs producing 2M complex coefficients;

- the reverse Fourier transform of said 2M complex coefficients producing 2M complex transform coefficients $C_{0,j}$ to $C_{2M-1,j}$;

- for each of the M pairs $(C_{k,j}, C_{(k+M),j})$ of said transform coefficients, the computation of 2L weighted coefficients, the weighing coefficients representing

said prototype function;

- the addition of the result of each of said weighted 2LM values to the contents of the 2LM distinct memory zones so as to gradually build the samples to be transmitted constituting the symbols j, (j+1), (j+2),... (j+2L-1);

- the sending of M samples corresponding to the M oldest contents of said memory zones and then the resetting of the contents of said M memory zones.

In general, said steps will be implemented at the rate τ_0/M of the samples.

The checking of the storage means is very simple. Thus, each sending step may be followed by a step for the updating of said memory locations comprising:

- a physical shifting of the contents of each of said memory locations if the latter are elements of a shift register; or

- an updating of the write and read addresses of said memory locations, if the latter are elements of â RAM.

According to an advantageous characteristic of the invention, said coefficients representing data elements to be transmitted are obtained by the implementation of a mathematical transform comprising the following steps:

- the application of a real reverse Fourier transform;

- the circular permutation of the result of this reverse transform by M/2 coefficients leftwards;

- the multiplication of each of said coefficients by i^n.

It is thus possible to obtain complex transform coefficients from an FFT with real inputs. Again, this makes it possible to limit the number of operations performed.

It is furthermore possible to simplify the computations by slightly modifying the equation of the signal centered on the frequency $M\nu_0$ so that it is written as follows:

$$s(t) = \sum_{n} \sum_{m=0}^{2M-1} a_{m,n}(-1)^{m(n+L)} i^{m+n} e^{2i\pi m\nu_0 t} g(t - n\tau_0)$$

The invention also relates to the modulation devices implementing a modulation method of this kind.

According to a particular embodiment, this device comprises especially:

- means of mathematical transformation delivering said coefficients representing data elements to be transmitted at the rate $\tau_0/2M$ and in the following order $(C_{0,j}, C_{M+1,j}),\ldots(C_{M-1,j}, C_{2M-1,j})$;
- 2LM-M simultaneous read/write RAM type memory locations;
- N complex multipliers working at the rate $N\tau_0/2LM$, N being equal to 1, 2, 4,...or 2L.

Thus, the memory space is further reduced.

The invention also relates to a method for the demodulation of a received signal corresponding to a multicarrier emitted signal with a density $1/(\nu_0.\tau_0) = 2$. According to this method, an estimation of 2M real data elements transmitted at a given symbol time is reconstituted by means of the following steps:

- the sampling of said signal received at the sample frequency τ_0/M, delivering M complex samples received;
- the storage of each of said M complex samples received in a predetermined location of an input memory comprising 2ML complex locations, in which there have been previously memorized (2L-1)M samples received during the 2l-1 previous symbol times;
- the multiplication of the 2ML values contained in said input memory by coefficients representing said prototype function;
- temporal aliasing, by the summing up of 2M series of L results of multiplication, so as to obtain 2M complex values;
- the processing of said 2M complex values to form said estimations of the 2M real data elements transmitted.

Advantageously, the 2M complex values derived from the temporal aliasing step between the instants $(j+2L-1)\tau_0$ and $(j+2L)\tau_0$ are written as follows:

$$R_{k',j} = \sum_{q'=0}^{2L-1} \alpha'_{k,q}\, r_{k'+(j+q')M}$$

$$R_{k'+M,j} = \sum_{q'=0}^{2L-1} \beta'_{k,q}\, r_{k'+(j+q')M}$$

where:

$r_{k'+(j+q')M}$ represents the sample received at the instant $k'\tau_0+(j+q')\tau_0/M$;

$\alpha'_{k,q}$ and $\beta'_{k,q}$ are said weighting coefficients.

Most usually, the computations will be simplified because:

- $\alpha'_{k,q'} = 0$ for q' as an odd parity value;
- $\beta'_{k,q'} = 0$ for q' as an even parity value.

According to a preferred embodiment, said processing step comprises the following steps:

- the application of a mathematical transformation that is the reverse of the one performed during the modulation on said 2M complex values delivering 2M transformed values;
- the correction of phase and/or amplitude distortions due to the transmission channel;
- the extraction of the real part of said transformed complex values.

In general, said steps are implemented at the rate τ_0/M of the samples.

The invention also relates to the demodulation devices implementing this method. These devices comprise:

- means for the sampling of said received signal;
- means for the temporary storage of the complex sample functions comprising 2ML complex locations;
- means for the multiplication of said memorized samples by weighting coefficients representing said prototype function;
- temporal aliasing means summing up L weighting results so as to obtain 2M complex values;

- means for the processing of said complex values delivering an estimation of 2M real data elements transmitted at each symbol time.

It is possible to further reduce the memory space needed in this device by means of:

- storage means comprising 2ML-M simultaneous write/read RAM type complex memory locations;

- N complex multipliers working at the $N\tau_0/2LM$ rate, where N is equal to 1, 2, 4 ... or 2L;

- means of mathematical transformation working at the $\tau_0/2M$ rate, whose inputs $R_{o,j}$ to $R_{2M-1,j}$ are read in the order $(R_{0,j}, R_{M,j})$, $(R_{1,j}, R_{M+1,j})$,... $(R_{M-1,j}, R_{2M-1,j})$.

Finally, the invention more generally relates to a filtering method delivering series of M complex output values at regular intervals from 2L series of 2M complex input values,

said M complex values corresponding to a weighted sum of 2L of said complex input values to be processed,

comprising the following steps for each series of complex input values:

- the computation of 2LM linear combinations from said 2M complex coefficients obtained, the weighting coefficients being derived from 2L real or complex filters with a size M,

so as to obtain 2LM coefficients;

- the summing of each of the weighted values in a predetermined memory location out of a set of 2ML memory locations each containing a partial sum so as to gradually form said output values in said memory locations on a period corresponding to the reception of 2L series of complex input values.

The term "filtering" must of course be taken here in its general sense of processing or computation performed on data elements. This processing which comprises the computation of a weighted sum is done gradually.

5 - Description of a preferred embodiment

5-1 List of figures

Other features and advantages of the invention shall appear more clearly from the following description of a preferred embodiment of the invention given as a simple non-restrictive illustration, and from the appended drawings, of which:

- Figure 1 gives a general and simplified illustration of the method of modulation of the invention (step j) used to generate M samples;
- Figure 2 illustrates the gradual construction of the M samples where L=4; for the Iota waveform;
- Figure 3 gives a more detailed illustration of the working of the method of modulation of the invention for the instants j-1 to j+2;
- Figure 4 specifies the initiation of the procedure of modulation of Figure 3 where $L = 4$;
- Figure 5 is a schematic diagram of a complex IFFT circuit known per se;
- Figures 6A to 6C illustrate the optimized architectures implementing FIFO systems and respectively using a single multiplier (Figure 6A), L multipliers (Figure 6B) or 2L multipliers (Figure 6C);
- Figure 7 shows an optimized embodiment of the reverse FFT using a real input FFT;
- Figure 8 illustrates the working of the demodulation method of the invention when L=4;
- Figure 9 shows the general case of demodulation deduced directly from Figure 8;
- Figure 10 illustrates a corresponding demodulator architecture;
- Figures 11 to 12 show two modes of implementation of the reception filtering in the case of a FIFO structure respectively using L and 2L multipliers.

5-2 Notations

. Intercarrier spacing: ν_0.

. Intersymbol duration: τ_0.

. Density of the network: $1/(\nu_0\tau_0) = 2$.

. Band allocated to the signal: $W = 2M\nu_0$.

. Sampling frequency: $f_e = 1/T_e = M/\tau_0$.

. Length of truncation of the protocol function: $2L\tau_0$.

In theory, the prototype function is the temporal support and/or infinite sequential support. However, to implement the corresponding digital filter, this function must be truncated.

This is the case in OFDM/OQAM/NYQUIST (infinite temporal support) and in OFDM/OQAM/IOTA (infinite temporal and frequency supports). Typically, for the function Iota, $L = 4$ at the minimum. For a sampling at T_e defined here above, the digital function will have the length of $2LM$ real coefficients.

. Indices of the samples:

To be consistent with the formula given hereinafter, the following is noted:

$$
\begin{aligned}
x_k &= x\left(k\frac{\tau_0}{M} - L\tau_0\right) \\
x_{k+LM} &= x\left(k\frac{\tau_0}{M}\right)
\end{aligned}
\qquad (2)
$$

the prototype function $g(t)$, the emitted signal $s(t)$ and the emitted signal $\hat{\ }(t)$ may be substituted for $x(t)$.

5-3 Modulation algorithm

5-3-1 Principle

The baseband signal centered on the frequency $M\nu_0 = f_e/2$, is written as follows:

$$
s(t) = \sum_n \sum_{m=0}^{2M-1} \underbrace{a_{m,n} i^{m+n} e^{2i\pi m\nu_0 t} g(t - n\tau_0)}_{c_{m,n}} \qquad (3)
$$

A sample of the signal is therefore written as:

$$s\left(p\frac{\tau_0}{M}\right) = \sum_{n}\sum_{m=0}^{2M-1} a_{m,n}\, i^{m+n}\, e^{2i\pi\frac{mp}{2M}}\, \overline{g}\left((p-nM)\frac{\tau_0}{M}\right) \qquad (4)$$

With the notations introduced here above (formula (2)), we have, after computation:

$$s_p = \sum_{n}\sum_{m=0}^{2M-1} a_{m,n}\, i^{m+n} e^{2i\pi\frac{mp}{2M}} (-1)^{mL}\, g_{p-nM} \qquad (5)$$

Given the rapid decrease of the prototype function, only the samples indexed 0 to *2ML-1* are considered to be non-zero. We should therefore have $0 \le p-nM \le 2ML-1$. Taking $p = k+jM$ where $0 \le k \le M-1$, we obtain $j-(2L-1) \le n \le j$.

The equation (5) becomes:

$$s_{k+jM} = \sum_{n=j-(2L-1)}^{j}\sum_{m=0}^{2M-1} a_{m,n}\, i^{m+n} (-1)^{m(n+L)}\, e^{2i\pi\frac{m(k+(j-n)M)}{2M}}\, g_{k+(j-n)M} \qquad (6)$$

Finally, assuming $q = j-n$, we obtain the formula from which we derive the modulation algorithm:

$$s_{k+jM} = \underbrace{\sum_{q=0}^{2L-1} \underbrace{\sum_{m=0}^{2M-1} \underbrace{a_{m,(j-q)}\, i^{m+(j-q)} (-1)^{m(j-q+L)}}_{\text{Pre-modulation}}\, e^{2i\pi \frac{m(k+qM)}{2M}}}_{\text{FFT Inverse}} \cdot g_{k+qM}}_{\text{Pondcration par la fonction prototype g(t)}}$$

$$\text{avec} \begin{cases} 0 \le k \le M-1 \\ j \in \mathrm{Z} \end{cases}$$

(7)

Noting $c_{m,j-q}$ as the pre-modulated input values giving:

$$c_{m,j-q} = a_{m,(j-q)}\, i^{m+(j-q)} (-1)^{m(j-q+L)}$$

the equation (7) becomes:

$$s_{k+jM} = \sum_{q=0}^{2L-1} \sum_{m=0}^{2M-1} c_{m,j-q}\, e^{2i\pi \frac{m(k+qM)}{2M}}\, g_{k+qM} \qquad (8)$$

This formula leads to a modulation algorithm in three main steps:

- Pre-modulation of the data elements by means of a simple complex multiplication.
- Reverse Fourier transform (by IFFT algorithm).
- Filtering by the prototype function.

Here, as in the rest of the document, the term filtering is understood to mean an operation of weighting of the results of 2L reverse FFT operations by certain values of the prototype function, followed by an operation of summing of these weighted coefficients. In other words, this is a linear combination.

Here below, we present two possible modes of implementation. The second mode is optimal and is more precisely the object of the invention.

Although in practice, the work is done at the sample rate τ_0/M, we shall retain

the block structure of M samples to describe these modes of implementation with greater clarity.

5-3-2 Direct architecture

In view of the formula (8), it is necessary to perform $2L$ complex IFFT operations with a size $2M$ to generate M samples (corresponding to the duration of a multicarrier symbol τ_0).

However, the result of an IFFT comes into play on the computation of $2L$ consecutive blocks of samples. To compute the M current samples, it is therefore necessary to compute only the reverse Fourier transform of the $2M$ last data elements entered into the modulator, the results of the $2L$-1 other IFFT values having been computed in the previous steps and stored in the memory.

The modulation algorithm therefore comprises the following main steps:

- The pre-modulation of the $2M$ real inputs delivering $2M$ complex values.
- The reverse Fourier transform with a size of $2M$ complex values (IFFT algorithm).
- Storage of the result by re-updating a buffer with a size of $2L$*$2M$ complex values (containing the results of the $2L$ reverse FFT operations indicated in the computation).
- Filtering of the $2LM$ elements of the storage buffer by the prototype function.
- Sending of the M complex samples thus computed.

The requisite memory size is therefore:

- a RAM with a size of $2L$*$2M$ complex values (input buffer),
- a ROM with a size of ML+1 real values (weighting coefficients).

(The prototype function is chosen to be symmetrical, on the $2ML$ weighting coefficients, and only the ML+1 values are distinct.)

This first procedure reveals a waste of RAM type memory. The second architecture proposed shows that it is possible to reduce the size of the necessary RAM by more than half. This reduction is accompanied by a reduction in the number of

operations and therefore an increase in the processing speed.

5-3-3 Optimized architecture

It is possible to optimize the architecture of the modulator according to the invention, both at the level of the filtering by the prototype function and that of the reverse FFT. Indeed, in analyzing the formula (8), it can be ascertained that for each of the $2L$ IFFTs involved in the computation of the current block of M samples, only M points on $2M$ are used.

It is then possible to reduce the required RAM type memory by half by storing the data elements used for the computations of the different blocks of samples after filtering, and not before. Furthermore, the specific structure of the complex data elements at input of the reverse FFT ($a_{m,n}\,(-1)^{m(n+L)}\,i^{m+n}$) enables the use of a reverse FFT algorithm with real inputs.

In order to specify this method, we shall develop the formula (8):

$$s_{k+jM} = \sum_{q'=0}^{L-1} \sum_{m=0}^{2M-1} c_{m,j-2q'}\, e^{2i\pi \frac{m\,k}{2M}}\, g_{k+2q'M} + \sum_{m=0}^{2M-1} c_{m,j-(2q'+1)}\, e^{2i\pi \frac{m\,(k+M)}{2M}}\, g_{k+(2q'+1)M}$$

Let:

$$C_{k,n} = \sum_{m=0}^{2M-1} c_{m,n}\, e^{2i\pi \frac{m\,k}{2M}} \qquad (9.1)$$

and

$$C_{k+M,n} = \sum_{m=0}^{2M-1} c_{m,n}\, e^{2i\pi \frac{m\,(k+M)}{2M}} \qquad (9.2)$$

We have:

$$s_{k+jM} = \sum_{q'=0}^{L-1} \left[C_{k,j-2q'}\, g_{k+2q'M} + C_{k+M,j-(2q'+1)}\, g_{k+(2q'+1)M} \right] \qquad (10)$$

with $0 \le k \le M-1$

The equation (10) expresses the construction of M complex values from 2ML complex values. It can be written more generally:

$$s_{k+jM} = \sum_{q=0}^{2L-1} \left[\alpha_{k,q} C_{k,j-q} + \beta_{k,q} C_{k+M,j-q}\right] \qquad (11)$$

avec $0 \le k \le M-1$

In the embodiment described,

$$\alpha_{k,q} = \begin{cases} 0 & \text{si q est impair} \\ g_{k+qM} & \text{si q est pair} \end{cases} \quad \text{et } \beta_{k,q} = \begin{cases} g_{k+qM} & \text{si q est impair} \\ 0 & \text{si q est pair} \end{cases}$$

To generate *M* samples according to this modulation algorithm, it is therefore possible to proceed as illustrated in Figure 1 (step j):

- Pre-modulation 11 of the 2*M* real inputs.
- Reverse Fourier transform 12 of the 2*M* complex data elements thus obtained so as to generate $C_{k,j}$ and $C_{k+M,j}$.
- A weighting 13 (corresponding to the application of the prototype function) of the result of the reverse Fourier transform by the prototype function: *L* parallel weighting operations.

The L weighting vectors, with a size 2*M*, have the following coefficients:

• $[g_0,\dots, g_{2M-1}]$, $[g_{2M},\dots, g_{4M-1}]$,…,$[g_{2LM-2M},\dots, g_{2LM-1}]$.

- The addition 14 of these weighting results to the output buffer of with a size of 2*ML*.complex values
- The shifting 15 of the output buffer with the sending of *M* samples, corresponding to the *M* oldest values contained in the buffer.

A sample of the signal to be transmitted represents a sum of 2*L* weighted IFFT results. Each block of *M* consecutive memory slots of the output buffer contains *M* partial sums of $2L$-m_{block} terms each, where m_{block} varies from 1 to 2*L* ($m_{block} = 2L$ corresponds to the "all at zero" block, due to the buffer shift operation (step 14) at the

instant $(j-1)\tau_0$). The $2ML$ elements coming from the L parallel weighting operations are herein added to the $2ML$ elements of the buffer.

After this operation, the M partial sums of the buffer corresponding to $m_{block} = 1$ are completed, namely the M current samples are computed and may therefore be transmitted.

This operation is described in Figure 2, where L=4. Each line illustrates the situation of the construction buffer of the data elements to be transmitted, at a given instant. It is necessary to have 2L consecutive symbol times to gradually construct a sample to be transmitted.

The waveform 2L shown corresponds to the Iota function. It is represented by the 2L vectors of coefficients 22 $[g_k]$ to $[g_{k+7M}]$, where the index k varies from 0 to M-1.

At each instant, the $2M$ coefficients at input are multiplied (23) by the coefficients 22 and then added up (24) each to a partial sum.

The M partial sums complemented at the step 15 are transmitted, the contents of the buffer are shifted by M memory slots (so as to ensure the right order of computation of the next M samples) and M zeros are inserted in the M vacant memory slots.

The diagonal 25 thus illustrates the computation of S_{k+jM}.

Figure 3 gives a more detailed view of the working of this algorithm for the instants j-1 to j+2. If we consider the instant j, the coefficient $a_{m,j}$ to be transmitted supplies the pre-modulation module 31, which gives the reverse FFT 32 the coefficients $c_{m,j}$. The reverse FFT delivers the $C_{k,j}$ and $C_{k+M,j}$ values (the index k varies from 0 to M-1) subjected to the weighting 33 (the weighting operations in parallel) to deliver the results 34 which are summed up in an output buffer 35.

Figure 3 gives an indication of the exact contents of these output buffers.

Figure 4 illustrates the triggering of this modulation procedure where $L = 4$.

The architecture of the modulator corresponding to the above algorithm presented here above must therefore comprise:

a ROM with a size of $ML+1$ real values containing the coefficients of the filter,

a RAM with a size of $2ML$ complex values corresponding to the output buffer,

a complex FFT circuit (achieving a reverse FFT) with a size $2M$.

To increase the processing speed, the weighting operations will be made parallel by using L RAMs with a size $2M$ associated with L multipliers or even $2L$ RAMs with a size of M complex values associated with $2L$ multipliers instead of one RAM with $2ML$ complex values.

The complexity of the modulation circuit is therefore:

- for the filtering:

In order to carry out the filtering, we multiply the results of the complex reverse FFT by the $2ML$ coefficients of the prototype function, by carrying out L weighting operations in parallel, including the result of the output buffer. Given that the coefficients of the prototype function are real, we have $(2\times 2ML)$ real multiplications and $2ML$ complex additions or $4ML$ real additions. The size of the output buffer is then $2ML$ complex memories or $4ML$ real memories.

- for the IFFT transform:

The results indicated in the following table relate to a conventional complex IFFT circuit whose schematic diagram is given in Figure 5. It comprises an input buffer 51, receiving 2M inputs, a computation unit 52 supplied by coefficients stored in the ROM type memory 53 and computed values stored in a RAM type memory 54 that deliver 2M outputs. A control module drives these different elements.

This table gives an estimation of the operations and equipment needed for the modulation part:

Modulation	*Addition Operations (real)*	*Multiplication Operations (real)*	*RAM (real)*	*ROM (real)*	*FIFO (real)*
Pre-modulation	–	–	–	–	–

Reverse FFT	$6M(1+\log_2 M)$	$4M(1+\log_2 M)$	$8M$	$2M$	–
Filtering	$4ML$	$4ML$	$4ML$	$ML+1$	–

It will be noted that no multiplication or addition is needed for the pre-modulation because the simple complex multiplication to be found at this stage is expressed, at the level of the architecture, by permutations of real and imaginary parts as well as changes of sign.

According to one variant of the invention, an additional gain in memory space may be obtained. It is indeed possible to use only ($2L$-1) RAMs with M complex values (total storage: $2ML$-M complex values instead of $2ML$). To do this, at the step j, a reading is done of the M samples to be transmitted into the corresponding RAM gradually, and the M complex values $C_{k+M,j}g_{k+(2L-1)M}$ are written progressively at the same addresses. To carry out this filtering operation, it is possible, as required, to use RAMs or FIFOs.

Figures 6A to 6C illustrate this method in the case where a FIFO structure is chosen.

In the case of Figure 6A, a single multiplier 61 is implemented. It multiplies data elements delivered by the reverse FFT by the weighting coefficients and supplies an adder 62 that also receives the output of the FIFO memory 63 containing 2ML-M complex values. This FIFO 63 is supplied by the result of the addition 62. A control module 64 enables the output of the FIFO to be directed outwards to deliver the M complex values ready to be transmitted 65.

It is possible to use N parallel-connected multipliers, where N = 1,2,4,...2L.

Thus, in the case of Figure 6B, L(=4) multipliers 61_1 to 61_4 are implemented in parallel. They are supplied alternatively with one or the other of the weighting coefficients associated with them.

Each of them supplies an adder 62_1 to 62_4 which also receives data elements from the 2L FIFO memories 63_1 to 63_7 each comprising M complex values. The FIFO memory 63_1 delivers the M complex outputs. Selection means 66 enable the selection

of a FIFO memory to be taken into account at each point in time.

Figure 6C shows the implementation of 2L (=8) multipliers. In this case, the structure no longer requires the presence of control means. The 2L FIFO memories 63_1 to 63_7 are each supplied by a multiplier 61_1 to 61_8, associated with its own weighting coefficient and associated with an adder 62_1 to 62_8.

It must be noted that the reduction of the memory space needed for the output buffer is valuable only if the following two conditions are met:

- the algorithm used to obtain the reverse FFT arranges its output in the optimum order $C_{0,j},C_{M,j},C_{1,j},C_{M+1,j},\ldots,C_{M-1,j},C_{2M-1}$ and works at the rate $\tau_0/(2M)$.

  Indeed, in the case of outputs arranged in the reverse bit order or even in the natural order, $C_{0,j},C_{1,j},\ldots C_{2M-2,j},C_{2M-1,j}$, the proposed gain in memory due to this simultaneous reading and writing of the output buffer then requires the reordering of the outputs of the reverse FFT in the optimum order which requires a storage at output of the FFT. In either case, the gain in memory will be negligible or even zero.

- The multipliers used, to prevent any storage of the outputs of the reverse FFT, work at a high speed: the rate of operation of N parallel-connected multipliers must be equal to $N\tau_0/(2LM)$, for N = 1,2,4,...2L.

According to another variant of the invention, it is possible to optimize the revere FFT. Given the « particular » complex character of the inputs $(a_{m,n}(-1)^{m(n+L)}i^{m+n})$ of the reverse FFT at transmission, it is possible to use an FFT algorithm with real inputs.

It is known that phase-shifting the inputs x_m of an FFT with a size $2M$, by i^m amounts to applying a circular permutation to its outputs y_k by $M/2$ leftwards. By applying this result, it can be clearly seen that the pre-modulation step:

$$(a_{m,n}i^{m+n}(-1)^{m(n+L)})$$

followed by the complex reverse FFT can be done as illustrated in Figure 7 in the

following steps:

- real reverse FFT 71 of the data elements $(-1)^{m(n+L)}$ $a_{m,n,}$
- circular permutation 72 by M/2 of the outputs,
- multiplication 73 by i^n.

An algorithm of this kind enables a reduction by half of the memory space needed for the FFT as well as the number of operations. Figure 5 shows these three operations.

It can be noted that the operation of multiplication by $(-1)^{m(n+L)}$ has been omitted. Indeed, it can be avoided.

At transmission, to generate the baseband signal s(t) (equation 1) digitally, the values of $a_{m,n}$ must be multiplied by $(-1)^{m(n+L)}$. In reception, the estimation of the data requires this multiplication again as shall be seen hereinafter.

Given the fact that the withdrawal of this multiplier term has no effect on the orthogonality of the time-frequency translated values, it is possible to remove the need for this multiplication. This amounts then to generating the baseband signal centered on the frequency $M\nu_0 = f_c/2$ according to:

$$s(t) = \sum_{n} \sum_{m=0}^{2M-1} a_{m,n} (-1)^{m(n+L)} e^{i\varphi_{m,n}} e^{2i\pi m\nu_0 t} g(t - n\tau_0) .$$

6 - Demodulation

The method of demodulation must enable a recovery of the useful information transmitted through the samples of the signal received in reception. It is assumed here that the "Doppler-delay" channel (the most general case) of the transfer function T(f,t) is perfectly estimated and that it is locally likened to a complex multiplier channel $T_{m,j} = \rho_{m,j} e^{i\theta_{m,j}}$.

Given the orthogonality of the "time-frequency" translated functions of the prototype function, the information sent at the instant $j\tau_0$, on the carrier m is thus estimated:

$$\hat{a}_{m,j} = \sum e \frac{1}{\rho_{m,j}} e^{-i\theta_{m,j}} \quad r(t) g^{*}_{m,j}(t) dt \qquad (12)$$

In practice, we work on the versions sampled at $\frac{\tau_0}{M} = \frac{1}{W}$ of the received signal, the demodulation function then becomes:

$$\hat{a}_{m,j} \cup \sum e \frac{1}{\rho_{m,j}} e^{-i\theta_{m,j}} (-i)^{m+j} \frac{1}{W} \sum_{p \in Z} \overline{r}\, p \frac{\tau_0}{M} e^{-2i\pi n \frac{p}{2M}} \overline{g} (p - jM) \frac{\tau_0}{M} \qquad (13)$$

Resuming the notations given by the formula (2) and taking account of the limited number of coefficients representing the prototype function ($2ML$), we obtain a demodulation formula as follows:

$$\hat{a}_{m,j} \cup \sum e \underbrace{\frac{1}{\rho_{m,j}} \frac{e^{-i\theta_{m,j}} (-i)^{m+j} (-1)^{m(j+L)}}{W}}_{\text{Phase and amplitude correction}} \underbrace{\sum_{k=0}^{2M-1} \underbrace{\sum_{q=0}^{L-1} r_{k+jM+2qM}\, g_{k+2qM}}_{\text{Weighting by the prototype function}} e^{-2i\pi n \frac{k}{2M}}}_{\text{Complex FFT}} \qquad ($$

with
$$p = jM + 2qM + k$$
$$0 \leq k \leq 2M - 1$$
$$0 \leq q \leq L - 1$$

The formula (14) suggests five steps for the fast demodulation algorithm.:

- weighting of samples received by the prototype function,
- temporal aliasing,
- 2M sized complex FTT,
- phase and amplitude correction,
- extraction of the real part.

The solution proposed according to the invention to minimize the memory space taken up by the filtering (weighting and temporal aliasing) in reception is as follows:

- inserting the M samples received in an input buffer with a size of $2ML$ complex FFT functions,
- multiplying the data elements of this buffer by the coefficients representing the prototype function,
- summing the results of these multiplications (temporal aliasing),
- applying a direct Fourier transform to the $2M$ complex values thus obtained,
- correcting the result of this FFT in phase and amplitude,
- extracting the real part.

It must be noted that this technique is independent of the way in which the signal has been constructed at transmission. It can be applied to the reception of any type of OFDM/OQAM multicarrier signal.

In order to illustrate the working of this algorithm, we shall break down the complex $2M$ sized complex signals into two M sized complex sub-signals each, as follows:

$$r_{k+jM+2qM} = r_{k'+jM+2qM}\,\mathbb{1}_{\{k\in\{0,\dots,M-1\}\}} + r_{(k'+M)+jM+2qM}\,\mathbb{1}_{\{k\in\{M,\dots,2M-1\}\}}$$
$$\text{with}\quad \begin{array}{l} 0 \le k \le 2M-1 \\ 0 \le k' \le M-1 \end{array} \qquad (15.1)$$

and

$$g_{k+jM+2qM} = g_{k'+jM+2qM}\,\mathbb{1}_{\{k\in\{0,\dots,M-1\}\}} + g_{(k'+M)+jM+2qM}\,\mathbb{1}_{\{k\in\{M,\dots,2M-1\}\}}$$
$$\text{with}\quad \begin{array}{l} 0 \le k \le 2M-1 \\ 0 \le k' \le M-1 \end{array} \qquad (15.2)$$

The entry of FFT for its part will be referenced $R_{k,j} = \sum_{q=0}^{L-1} r_{k+jM+2qM} \cdot g_{k+2qM}$, k going from 0 to 2M-1.

The estimation of the data elements sent will start after a delay of $(2L-1)\tau_0$. It is necessary indeed that all the received samples comprising the data element $a_{m,j}$ should be stored in the input buffer before $\hat{a}_{m,j}$. is computed.

The notations (15.1) and (15.2) here above make it possible, when L=4 , the inputs of the FFT needed for the estimation of $a_{m,0}$, to write these equations in the form (with k' = 0...M-1):

$$R_{k',0} = r_{k'}g_{k'} + \quad + r_{k'+2M}g_{k'+2M} + \quad + r_{k'+4M}g_{k'+4M} + \quad + r_{k'+6M}g_{k'+6M}$$

$$R_{k'+M,0} = \quad r_{k'+M}g_{k'+M} + \quad + r_{k'+3M}g_{k'+3M} + \quad + r_{k'+5M}g_{k'+5M} + \quad + r_{k'+7M}g_{k'+7M}$$

Similarly, the inputs of the FFT corresponding to the estimation of the values $a_{m,1}$ (m=0 to 2M-1) are thus built:

$$R_{k',1} = r_{k'+M}g_{k'} + \quad + r_{k'+3M}g_{k'+2M} + \quad + r_{k'+5M}g_{k'+4M} + \quad + r_{k'+7M}g_{k'+6M}$$

$$R_{k'+M,1} = \quad r_{k'+2M}g_{k'+M} + \quad + r_{k'+4M}g_{k'+3M} + \quad + r_{k'+6M}g_{k'+5M} + \quad + r_{k'+8M}g_{k'+7M}$$

...

Figure 8 illustrates the working of the architecture proposed in the case where L=4. The general case is illustrated by Figure 9 and is deduced directly from Figure 8.

In this figure 8, the M samples 81 received at an given point in time are stored in an input buffer 82. At each symbol time, the data elements contained in this buffer 82 are multiplied (83) by the weighting coefficients 84 representing the waveform 85 (IOTA in the example) then added up (86) to carry out the aliasing.

The corresponding data elements R_{kjj} supply the FFT 87, performed on 2M complex samples. Then a phase correction 88 is done and then an extraction 89 of the real part.

Finally, a shift is made of the contents of the input buffer 82. Figure 8 presents the contents of this buffer for eight successive instants, corresponding to the production of the outputs $\hat{a}_{mj}$ à $\hat{a}_{mj+7}$.

The above formulae represent the case of the demodulator associated with an OFDM/OQAM modulator with a density 2. However, this architecture remains applicable to the case of the restitution of 2M complex values from M complex values

resulting from the general case of modulation illustrated by the formula (11). The associated general formula would be:

$$\begin{aligned} R_{k',j} &= \sum_{q'=0}^{2L-1} r_{k',j+q'}.\alpha'_{k',q'} \\ R_{k'+M,j} &= \sum_{q'=0}^{2L-1} r_{k',j+q'}.\beta'_{k',q'} \end{aligned} \quad \text{with} \quad k' \in \{0,\ldots,M-1\} \qquad (16)$$

The above algorithm requires the following means:

- a RAM with a size of $2ML$ complex values (input buffer),
- a ROM with a size of (ML+1) real values (coefficients of the digital filter),
- 1, L or 2L complex multipliers depending on the degree of parallel performance of the weighting operations,
- a complex FFT circuit with a size $2M$.

Figure 10 illustrates the architecture proposed.

The input buffer, capable of containing 2ML complex values, receives M samples at each τ_0. The weighting by the prototype function is done by the multiplication operations 102 and then the aliasing is done by means of two adders 103_1 and 103_2, which supply a buffer 104 of 2M values supplying the complex FFT 105.

At the end of the FFT operation 105, a phase and amplitude correction 106 is performed and then the real part is selected at 107 to give the 2M real values transmitted.

Just as at transmission, it is possible to perform the weighting operations in parallel (complex multiplication) by using $2L$ buffers with a size of M complex values associated with L, or $2L$ multipliers, rather than a single one with a size of $2ML$. These aspects are illustrated respectively by Figures 11 and 12. The operation is deduced directly from the one described with reference to Figures 6B and 6C for transmission.

It is possible to use only ($2L$-1) RAMs of M complex values (total storage: $2ML-M$ complex values instead of $2ML$) to store the received samples. It is necessary,

at the step j, to read the k^{th} ($k=0..M-1$) sample received at the step $(j-(2L-1))$, and write the k^{th} current sample at the same address.

To perform this operation, it is possible, as needed, to use RAMs or FIFO memories. Figures 11 and 12 implement this method in the case of a FIFO structure.

Once again, as at transmission, it must be noted that the reduction of the memory space needed for the input buffer is useful only if the following two conditions are met:

- the algorithm used to achieve the FFT works at the rate $\tau_0/(2M)$ with the inputs arriving in the « optimum » order $R_{0,j},R_{M,j},R_{1,j},R_{M+1,j},\ldots,R_{M-1,j},R_{2M-1,j}$. If not, a storage at the input of the FFT will be necessary and the memory gain will then be negligible or even zero,
- the multipliers used, also to prevent any storage of inputs of the FFT, work at high speed: the rate of operation of N multipliers in parallel must be equal to $N\tau_0/(2LM)$, for $N = 1,2,4,\ldots 2L$.

CLAIMS

1. Method for the modulation of a multicarrier signal with a density $1/(\nu_0.\tau_0)=2$, formed by successive symbols, each comprising M samples to be transmitted and constituted by a set of 2M orthogonal carrier frequencies in the real sense,

the interval between two neighboring carrier frequencies being equal to ν_0 and the interval between the times of transmission of two consecutive symbols, or the symbol time, being equal to τ_0,

each of said carrier frequencies being modulated according to one and the same modulation prototype function g(t) with a truncation length of $2L\tau_0$,

characterized in that it comprises, at each symbol time, the following steps:

- the obtaining of a set of 2M complex coefficients representing data to be transmitted;
- the computing of 2LM linear combinations from said 2M complex coefficients obtained, the weighting coefficients used in these combinations representing said prototype function g(t), so as to obtain 2LM coefficients;
- the summing of said 2LM coefficients weighted in the predetermined storage locations of a memory comprising 2LM storage locations representing 2L groups of M distinct partial sums,

so as to gradually form, in said storage locations, over a duration of $2L\tau_0$, M samples to be transmitted;

- the transmission of said samples to be transmitted.

2. Method of modulation according to claim 1, characterized in that a sample to be transmitted at the instant $j\tau_0 + k\tau_0/M$, referenced s_{k+jM} is written as follows:

$$s_{k+jM} = \sum_{q=0}^{2L-1} \left[\alpha_{k,q} C_{k,j-q} + \beta_{k,q} C_{k+M,j-q}\right]$$

where: $C_{o,j}$ to $C_{2M-1,j}$ are the 2M complex coefficients generated between the instants

$j\tau_0$ and $(j+1)\tau_0$;

$\alpha_{k,q}$ and $\beta_{k,q}$ are said weighting coefficients.

3. Method of modulation according to claim 2, characterized in that:

- $\alpha_{k,q} = 0$ for q as an odd parity number;
- $\beta_{k,q} = 0$ for q as an even parity number.

4. Method of modulation according to claim 3, characterized in that:it comprises, for the generation of a symbol with an index j formed by M samples, the following steps:

- the obtaining of 2M real inputs $a_{m,n}$ representing a source signal;
- the pre-modulation of each of said real inputs producing 2M complex coefficients;
- the reverse Fourier transform of said 2M complex coefficients producing 2M complex transformed coefficients $C_{0,j}$ to $C_{2M-1,j}$;
- for each of the M pairs $(C_{k,j}, C_{(k+M),j})$ of said transformed coefficients, the computation of 2L weighted coefficients, the weighing coefficients representing said prototype function;
- the addition of the result of each of said weighted 2LM values to the contents of the 2LM distinct memory zones so as to gradually build the samples to be transmitted constituting the symbols j, (j+1), (j+2),... (j+2L-1);
- the sending of M samples corresponding to the M oldest contents of said memory zones and then the resetting of the contents of said M memory zones.

5. Method of modulation according any of the claims 1 to 4, characterized in that said steps are implemented at the rate τ_0/M of the samples.

6. Method of modulation according to any of the claims 1 to 5, characterized in that said transmission step is followed by a step for the updating of said memory locations comprising:

- a physical shifting of the contents of each of said memory locations if the latter are elements of a shift register; or

- an updating of the write and read addresses of said memory locations, if the latter are elements of a RAM.

7. Method of modulation according to any of the claims 1 to 6, characterized in that said coefficients representing data elements to be transmitted are obtained by the implementation of a mathematical transform comprising the following steps:

- the application of a real reverse Fourier transform;
- the circular permutation of the result of this reverse transform by M/2 coefficients leftwards;
- the multiplication of each of said coefficients by i^n.

8. Method of modulation according to any of the claims 1 to 7, characterized in that the signal centered on the frequency $M\nu_0$ is written as follows:

$$s(t) = \sum_n \sum_{m=0}^{2M-1} a_{m,n}(-1)^{m(n+L)} i^{m+n} e^{2i\pi m\nu_0 t} g(t - n\tau_0)$$

9. Device for the modulation of a multicarrier signal with a density $1/(\nu_0.\tau_0)=2$, formed by successive symbols, each comprising M samples to be transmitted and constituted by a set of 2M orthogonal carrier frequencies in the real sense,

the interval between two neighboring carrier frequencies being equal to ν_0 and the interval between the times of transmission of two consecutive symbols, or the symbol time, being equal to τ_0,

each of said carrier frequencies being modulated according to one and the same modulation prototype function g(t) with a truncation length of $2L\tau_0$,

characterized in that it comprises:

- means for the temporary storage of 2M groups of M partial sums
- means for the weighting of 2M complex coefficients representing data elements to be transmitted by weighting coefficients representing said prototype function g(t)
- means for the summing of the weighted coefficients in respective predetermined memory locations of said temporary storage locations,

so as to gradually form said samples to be transmitted on a duration of $2L\tau_0$.

10. Modulation device according to claim 9, characterized in that it comprises:

- means of mathematical transformation delivering said coefficients representing data elements to be transmitted at the rate $\tau_0/2M$ and in the following order $(C_{0,j}, C_{M+1,j}),\ldots(C_{M-1,j}, C_{2M-1,j})$;
- 2LM-M simultaneous read/write RAM type memory locations;
- N complex multipliers working at the rate $N\tau_0/2LM$, N being equal to 1, 2, 4,...or 2L.

11. Method for the demodulation of a received signal corresponding to a transmitted multicarrier signal with a density $1/(\nu_0.\tau_0)=2$, formed by successive symbols, each comprising M samples to be transmitted and constituted by a set of 2M orthogonal carrier frequencies in the real sense,

the interval between two neighboring carrier frequencies being equal to ν_0 and the interval between the times of transmission of two consecutive symbols, or the symbol time, being equal to τ_0,

each of said carrier frequencies being modulated according to one and the same modulation prototype function g(t) with a truncation length of $2L\tau_0$,

characterized in that an estimation of 2M real data elements transmitted at a given symbol time is reconstituted by means of the following steps:

- the sampling of said signal received at the sample frequency τ_0/M, delivering M complex samples received;
- the storage of each of said M complex samples received in a predetermined location of an input memory comprising 2ML complex locations, in which there have been previously memorized (2L-1)M samples received during the 2l-1 previous symbol times;
- the multiplication of the 2ML values contained in said input memory by coefficients representing said prototype function;
- temporal aliasing, by the summing up of 2M series of L results of multiplication, so as to obtain 2M complex values;

- the processing of said 2M complex values to form said estimations of the 2M real data elements transmitted.

12. A demodulation method according to claim 11, characterized in that the 2M complex values derived from the temporal aliasing step between the instants $(j+2L-1)\tau_0$ and $(j+2L)\tau_0$ are written as follows:

$$R_{k,j} = \sum_{q'=0}^{2L-1} \alpha'_{k,q}\, r_{k'+(j+q')M}$$

$$R_{k+M,j} = \sum_{q'=0}^{2L-1} \beta'_{k,q}\, r_{k'+(j+q')M}$$

where:

$r_{k'+(j+q')M}$ represents the sample received at the instant $k'\tau_0+(j+q')\tau_0/M$;

$\alpha'_{k,q}$ and $\beta'_{k,q}$ are said weighting coefficients.

13. Demodulation method according to any of the claims 11 and 12, characterized in that :

- $\alpha'_{k,q'} = 0$ for q' as an odd parity value;
- $\beta'_{k,q'} = 0$ for q' as an even parity value.

14. Method according to any of the claims 11 to 13, characterized in that said processing step comprises the following steps:

- the application of a mathematical transformation that is the reverse of the one performed during the modulation on said 2M complex values delivering 2M transformed values;

- the correction of phase and/or amplitude distortions due to the transmission channel;

- the extraction of the real part of said transformed complex values.

15. Demodulation method according to any of the claims 11 to 14, characterized in that said steps are implemented at the rate τ_0/M of the samples.

16. Device for the demodulation of a received signal corresponding to a

transmitted multicarrier signal with a density $1/(\nu_0 \cdot \tau_0)=2$, formed by successive symbols, each comprising M samples to be transmitted and constituted by a set of 2M orthogonal carrier frequencies in the real sense,

the interval between two neighboring carrier frequencies being equal to ν_0 and the interval between the times of transmission of two consecutive symbols, or the symbol time, being equal to τ_0,

each of said carrier frequencies being modulated according to one and the same modulation prototype function g(t) with a truncation length of $2L\tau_0$,

characterized in that it comprises:

- means for the sampling of said received signal;
- means for the temporary storage of the complex sample functions comprising 2ML complex locations;
- means for the multiplication of said memorized samples by weighting coefficients representing said prototype function;
- temporal aliasing means summing up L weighting results so as to obtain 2M complex values;
- means for the processing of said complex values delivering an estimation of 2M real data elements transmitted at each symbol time.

17. Demodulation device according to claim 16, characterized in that it comprises:

- means of mathematical transformation that is the reverse of the transformation performed during the modulation on said 2M complex values;
- means for the correction of phase and/or amplitude distortions due to the transmission channel;
- means for the extraction of the real part of said transformed complex values

18. Demodulation device according to any of the claims 16 and 17, characterized in that it comprises:

- storage means comprising 2ML-M simultaneous write/read RAM type

complex memory locations;

- N complex multipliers working at the $N\tau_0/2LM$ rate, where N is equal to 1, 2, 4 ... or 2L;

- means of mathematical transformation working at the $\tau_0/2M$ rate, whose inputs $R_{o,j}$ to $R_{2M-1,j}$ are read in the order $(R_{0,j}, R_{M,j})$, $(R_{1,j}, R_{M+1,j})$,... $(R_{M-1,j}, R_{2M-1,j})$.

19. A filtering method delivering series of M complex output values at regular intervals from 2L series of 2M complex input values,

said M complex values corresponding to a weighted sum of 2L of said complex input values to be processed,

characterized in that it comprises the following steps for each series of complex input values:

- the computation of 2LM linear combinations from said 2M complex coefficients obtained, the weighting coefficients being derived from 2L complex or real filters with a size M,

so as to obtain 2LM coefficients;

- the summing of each of the weighted values in a predetermined memory location out of a set of 2ML memory locations each containing a partial sum so as to gradually form said output values in said memory locations on a period corresponding to the reception of 2L series of complex input values.

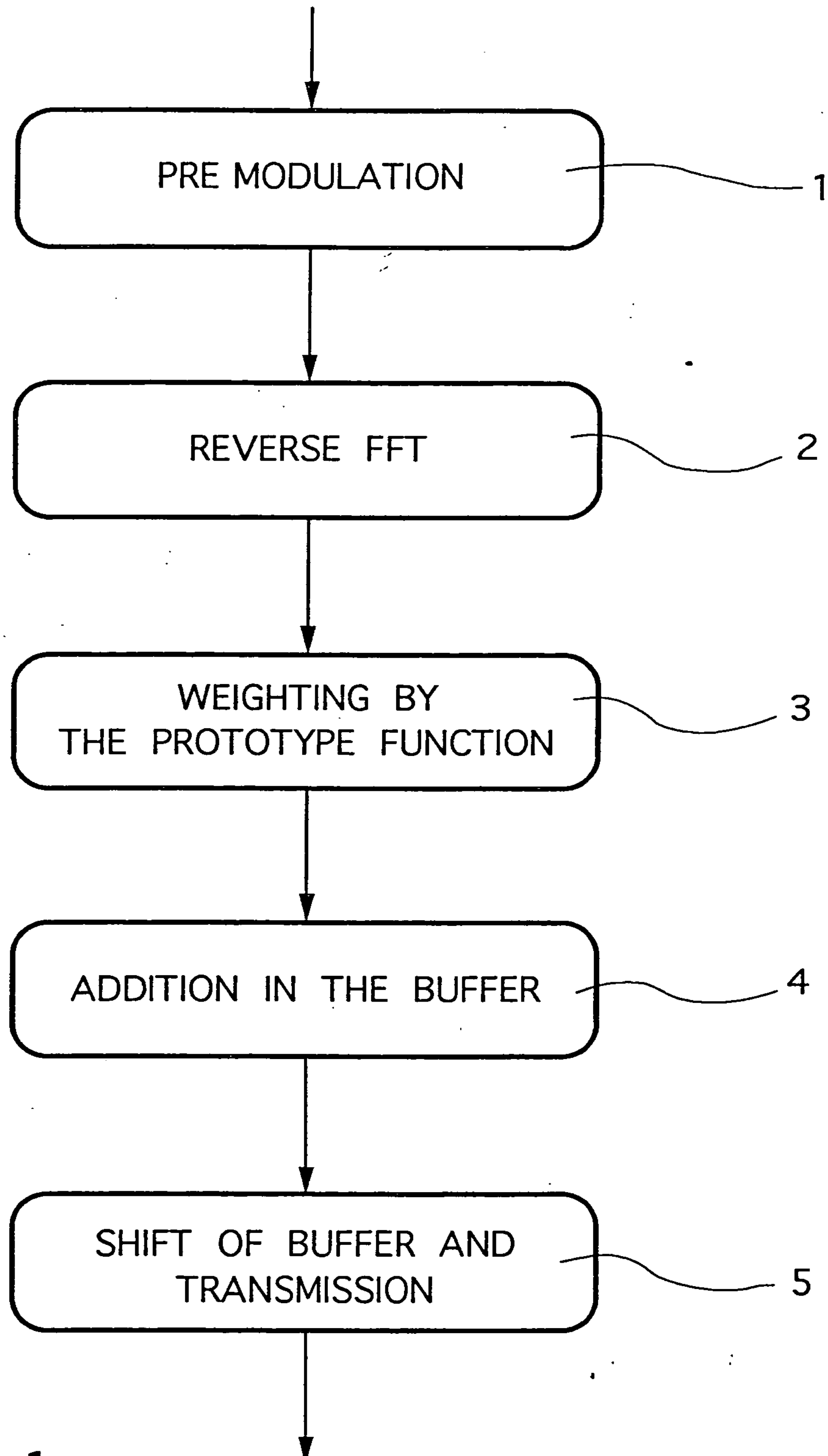

PRE MODULATION
1
REVERSE FFT
2
WEIGHTING BY THE PROTOTYPE FUNCTION
3
ADDITION IN THE BUFFER
4
SHIFT OF BUFFER AND TRANSMISSION
5

Fig. 1

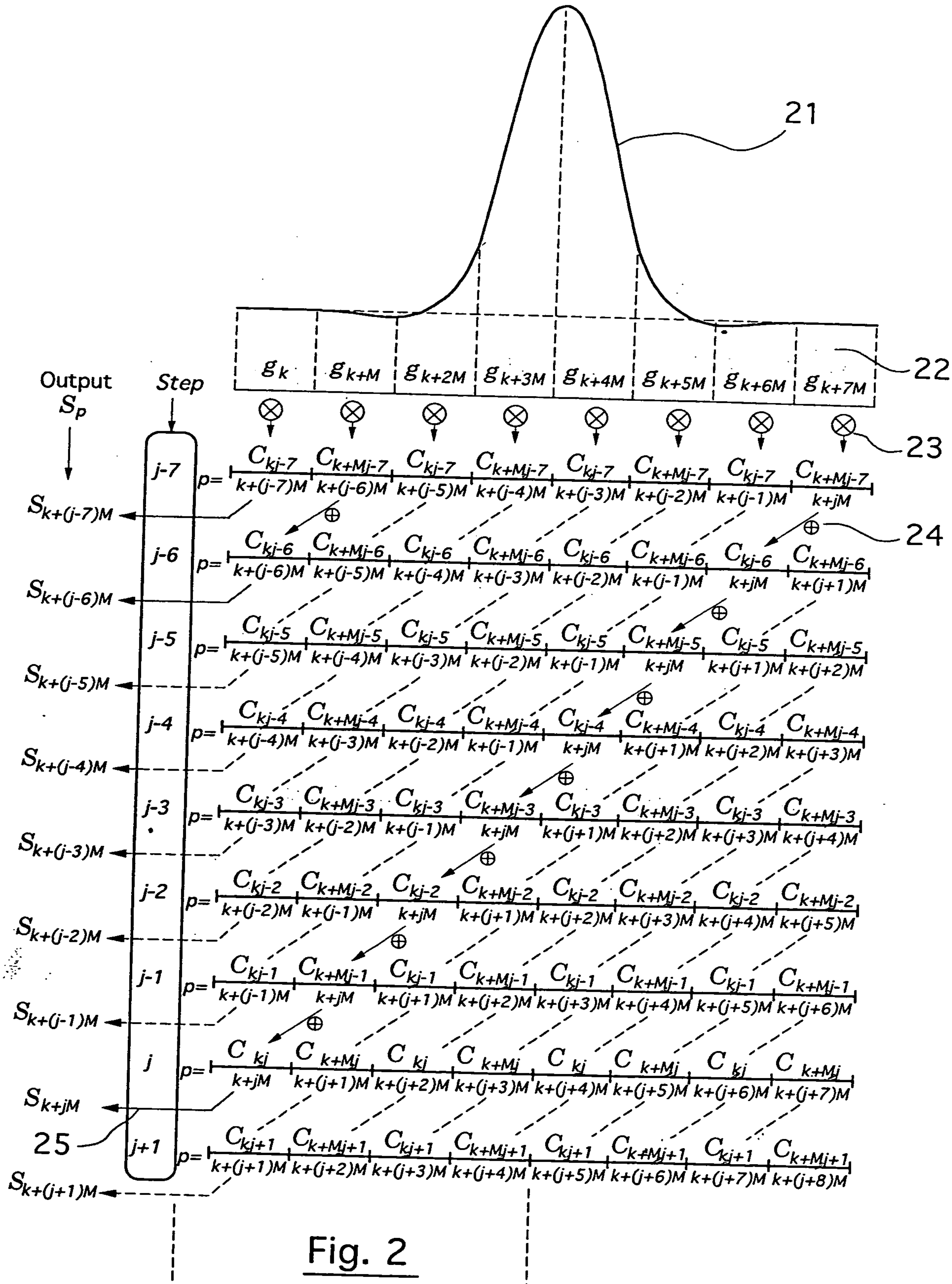

21
22
23
24
25
Output S_p
Step
g_k g_{k+M} g_{k+2M} g_{k+3M} g_{k+4M} g_{k+5M} g_{k+6M} g_{k+7M}
j-7
j-6
j-5
j-4
j-3
j-2
j-1
j
j+1
p=
C_{kj-7} C_{k+Mj-7}
C_{kj} C_{k+Mj}
C_{kj+1} C_{k+Mj+1}
$S_{k+(j-7)M}$
$S_{k+(j-6)M}$
$S_{k+(j-5)M}$
$S_{k+(j-4)M}$
$S_{k+(j-3)M}$
$S_{k+(j-2)M}$
$S_{k+(j-1)M}$
S_{k+jM}
$S_{k+(j+1)M}$

Fig. 2

APPROVED	O.G. FIG.	
BY	CLASS	SUBCLASS
DRAFTSMAN		

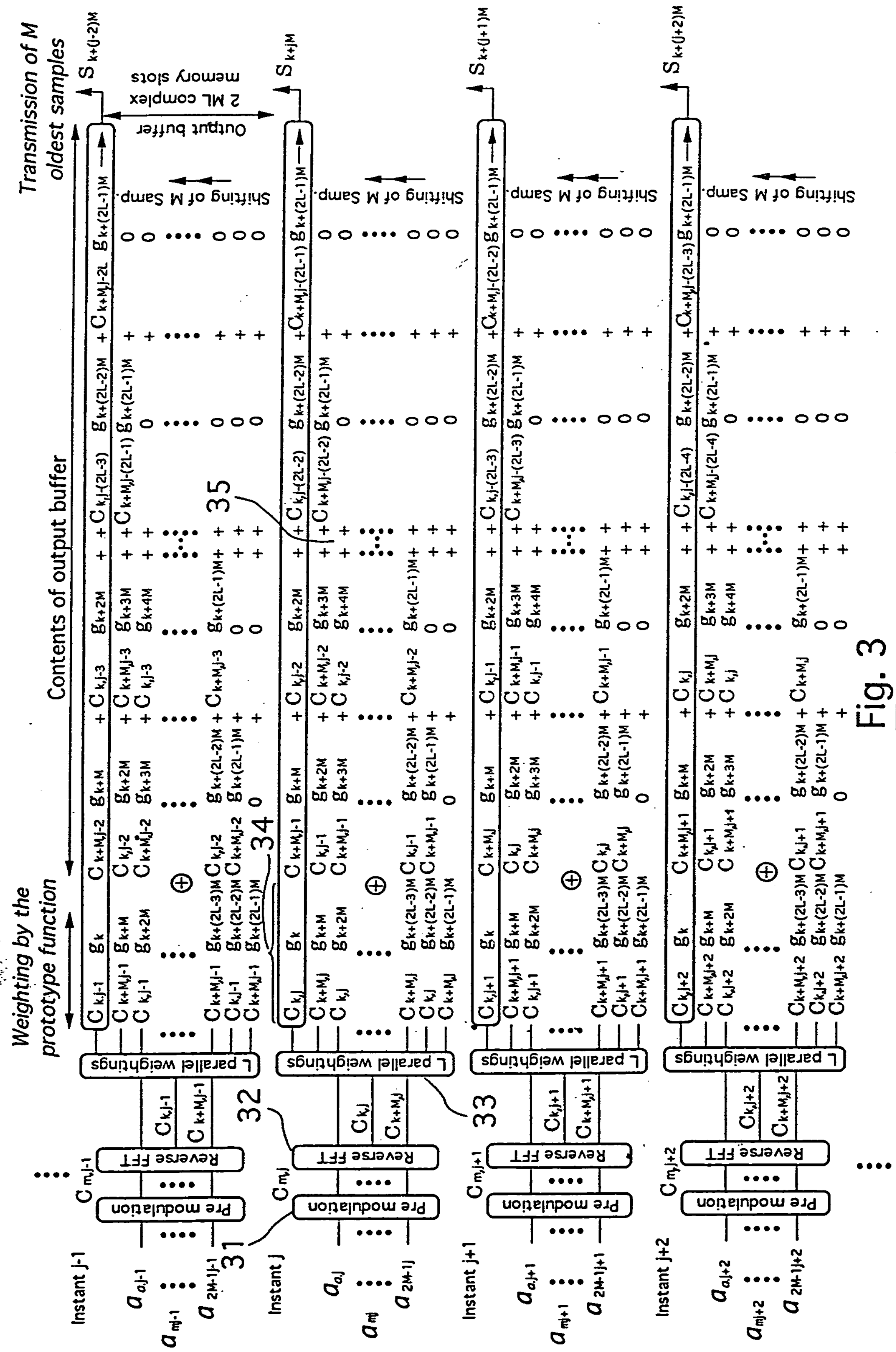


Fig. 3

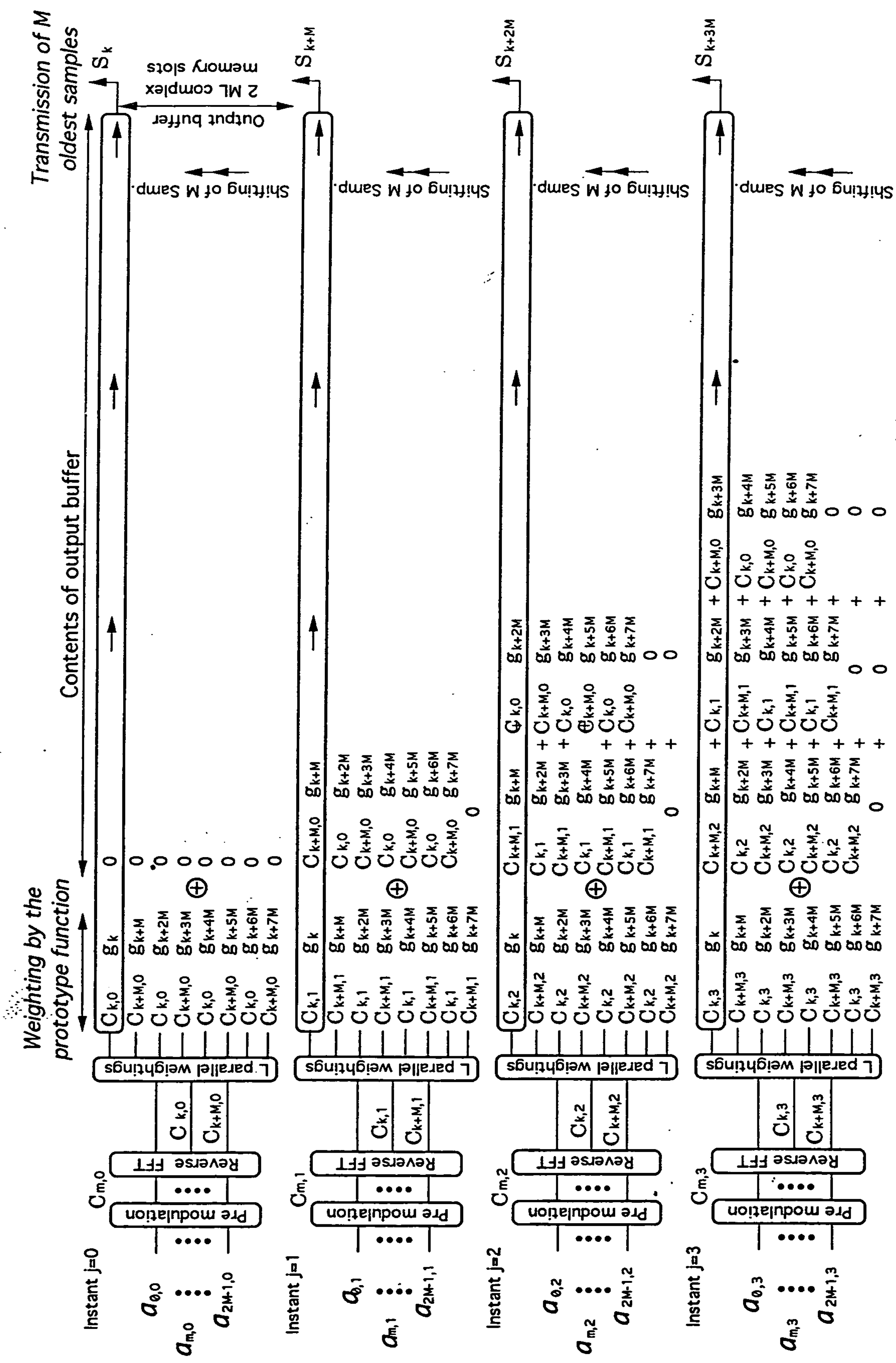

Transmission of M oldest samples
Contents of output buffer
Weighting by the prototype function
Output buffer
2 ML complex memory slots
Shifting of M Samp.
Instant j=0
Instant j=1
Instant j=2
Instant j=3
Pre modulation
Reverse FFT
L parallel weightings

Fig. 4

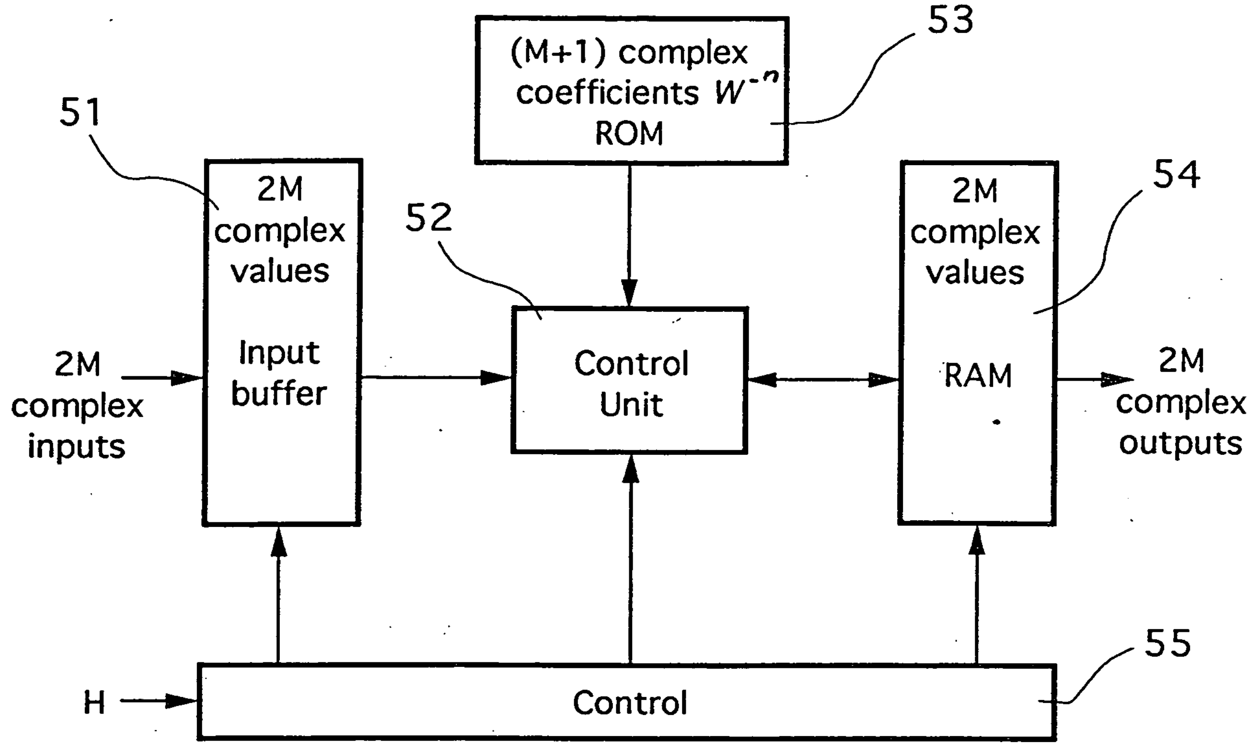

(M+1) complex coefficients W^{-n} ROM
53
51
2M complex values
Input buffer
52
Control Unit
2M complex values
RAM
54
2M complex inputs
2M complex outputs
H
Control
55

Fig. 5

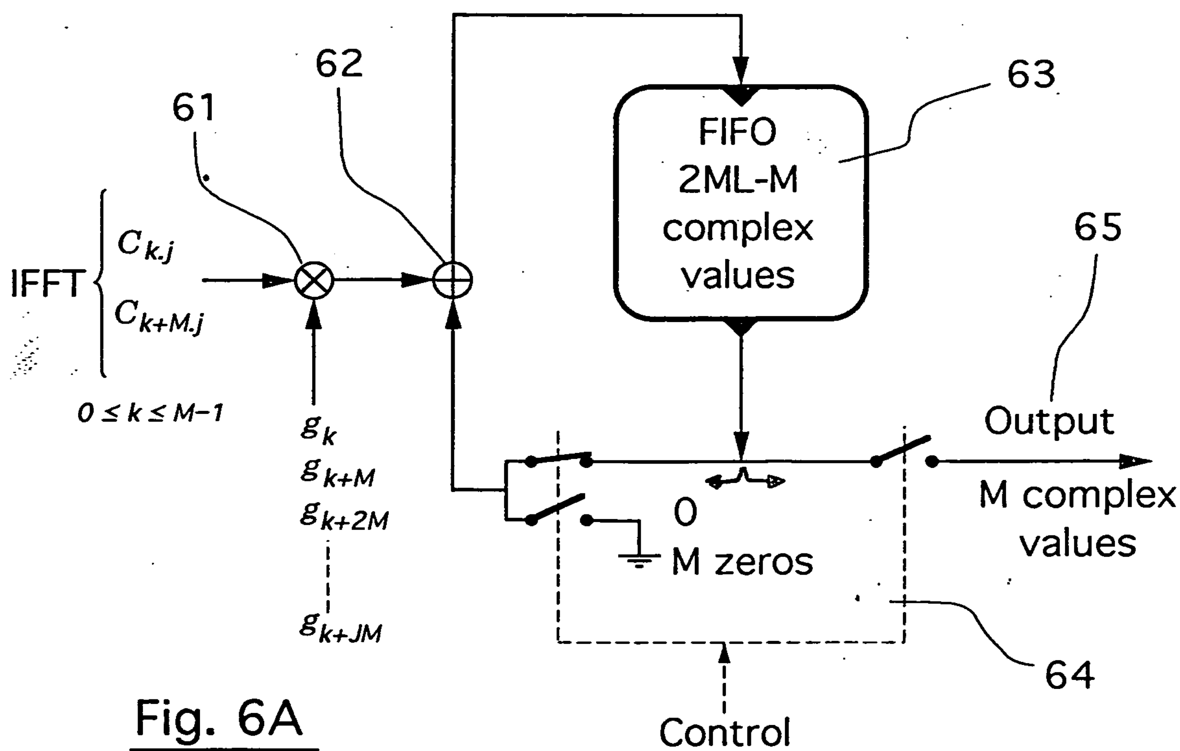

62
61
FIFO 2ML-M complex values
63
65
IFFT
$C_{k.j}$
$C_{k+M.j}$
$0 \leq k \leq M-1$
g_k
g_{k+M}
g_{k+2M}
g_{k+JM}
Output
M complex values
0
M zeros
64
Control

Fig. 6A

APPROVED BY DRAFTSMAN	O.G. FIG.	
	CLASS	SUBCLASS

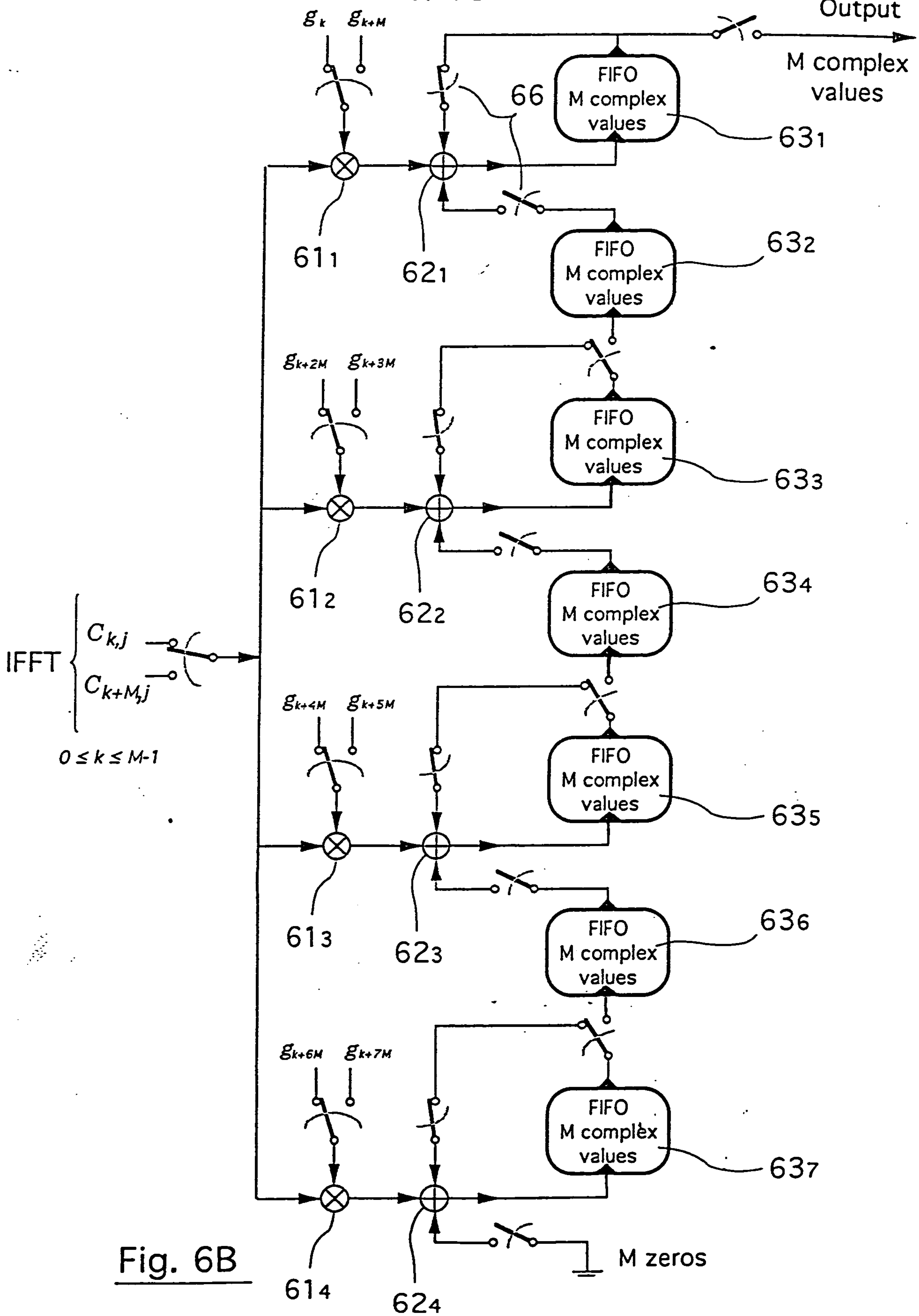
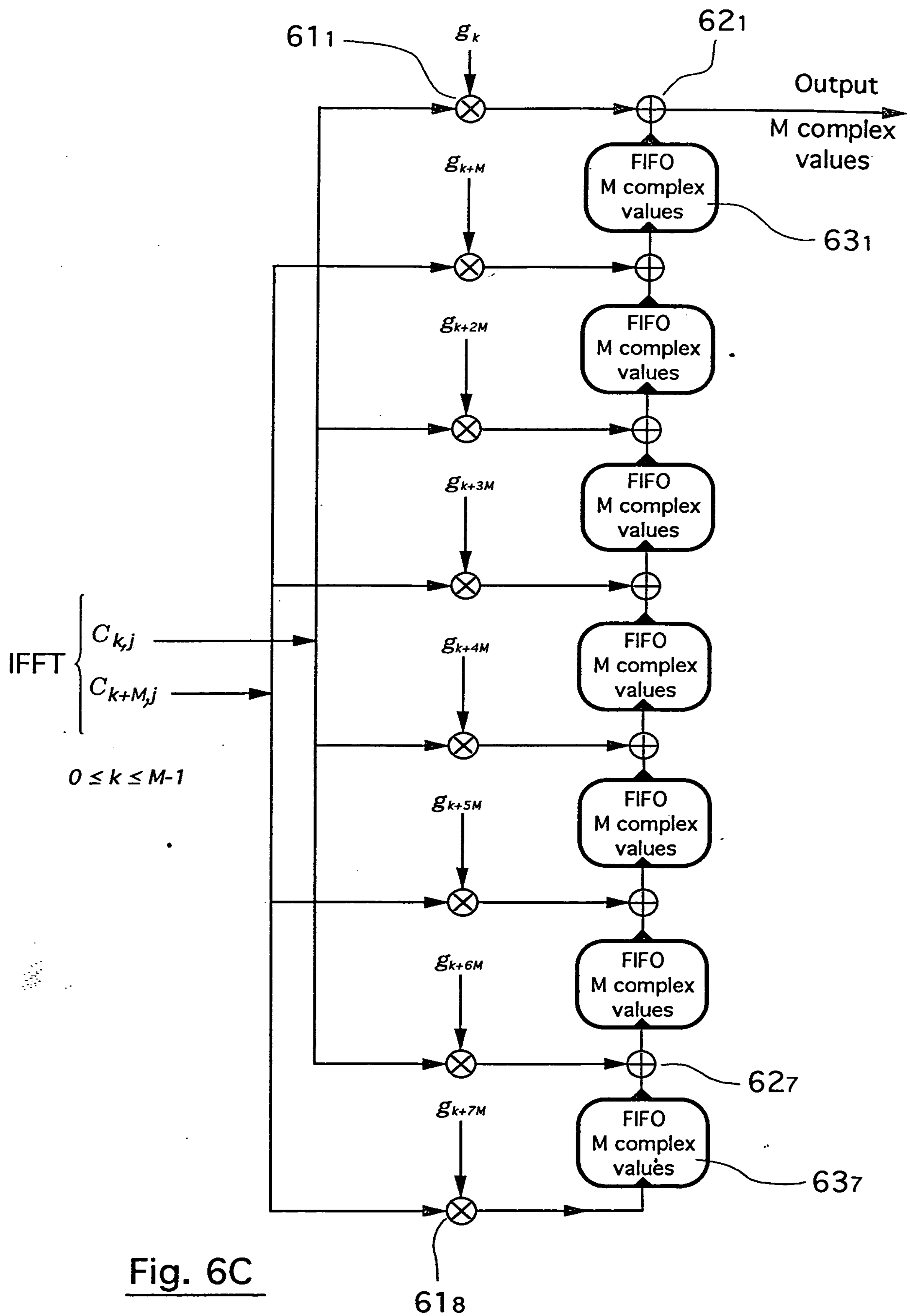


Fig. 6B



61₁
g_k
62₁
Output
M complex values
g_{k+M}
FIFO M complex values
63₁
g_{k+2M}
g_{k+3M}
g_{k+4M}
g_{k+5M}
g_{k+6M}
g_{k+7M}
IFFT
$C_{k,j}$
$C_{k+M,j}$
$0 \le k \le M-1$
62₇
63₇
61₈

Fig. 6C

APPROVED BY DRAFTSMAN | O.G. FIG. | CLASS | SUBCLASS

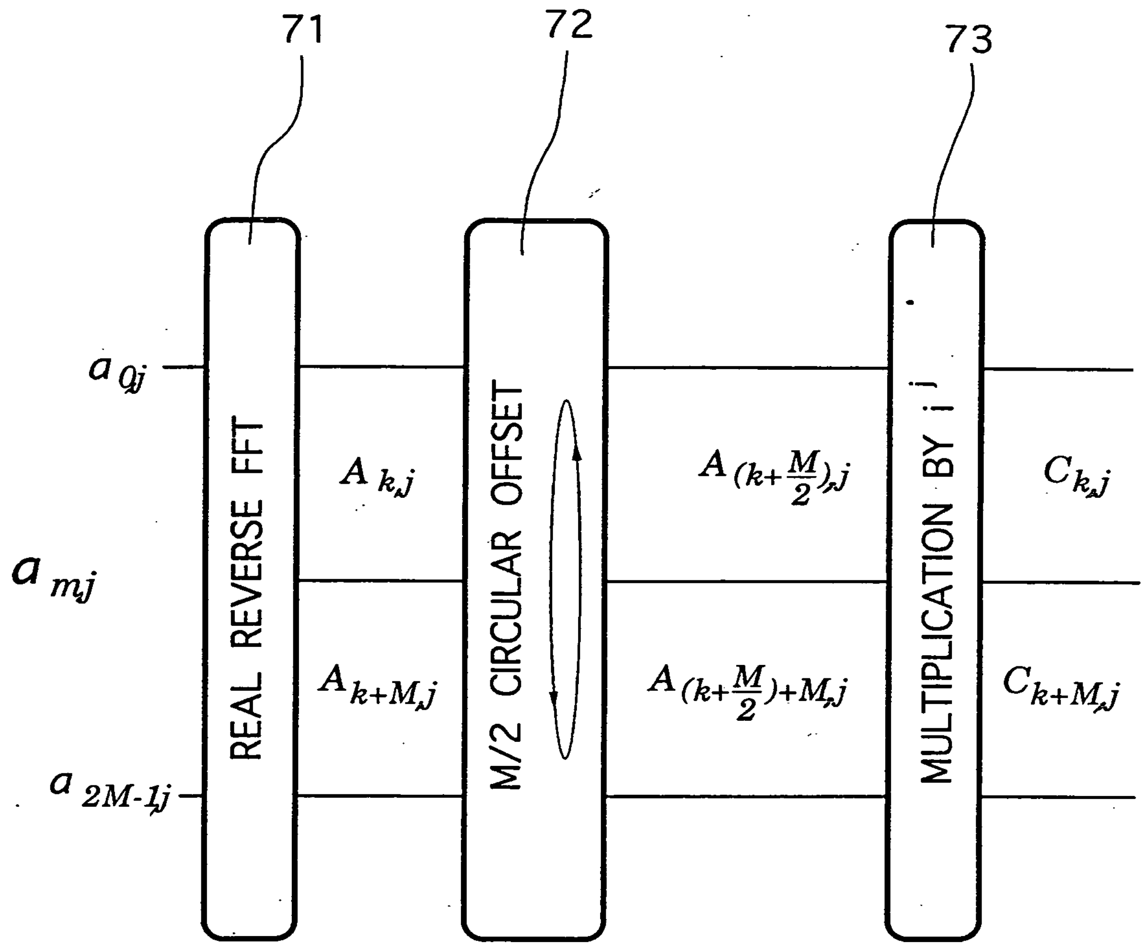
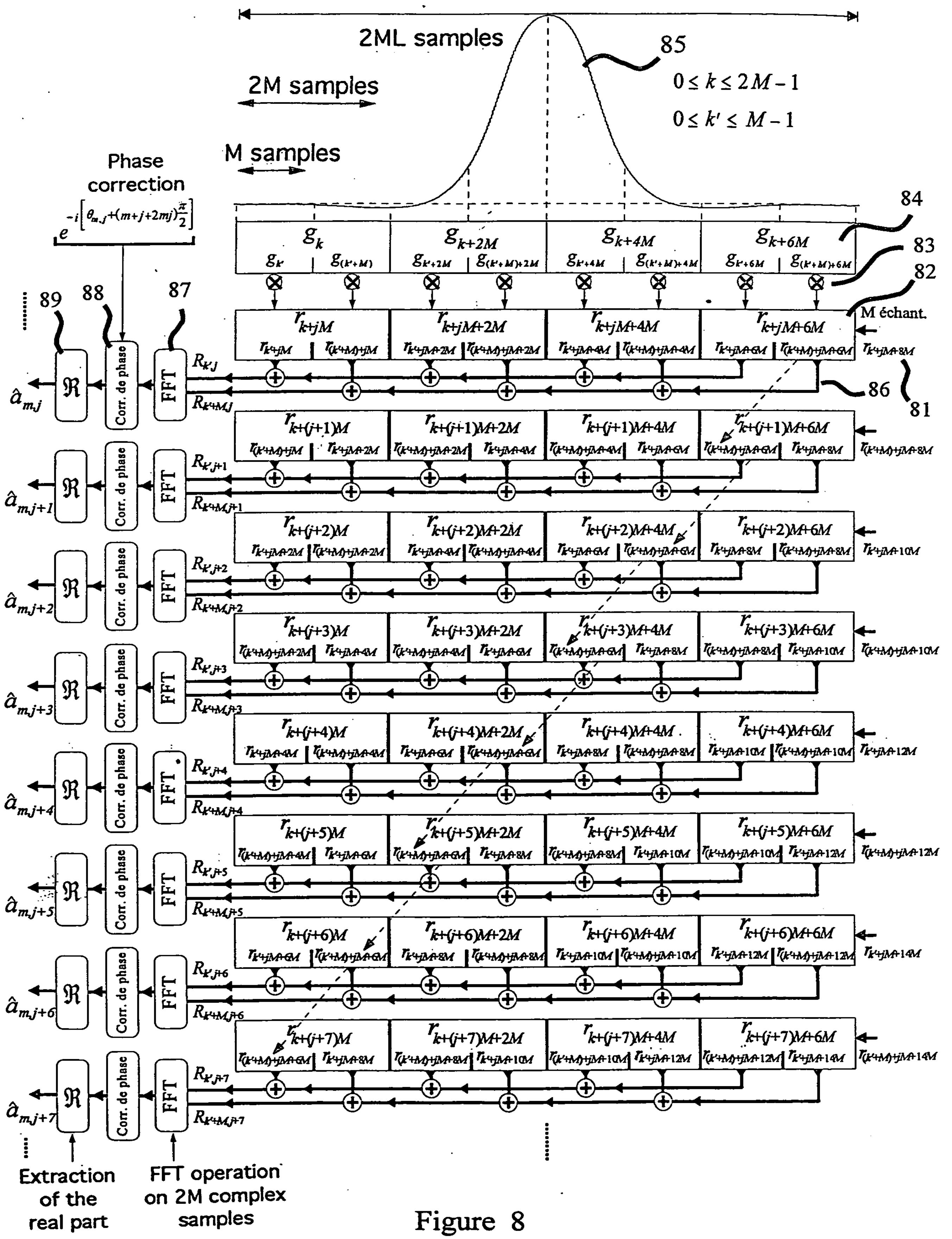
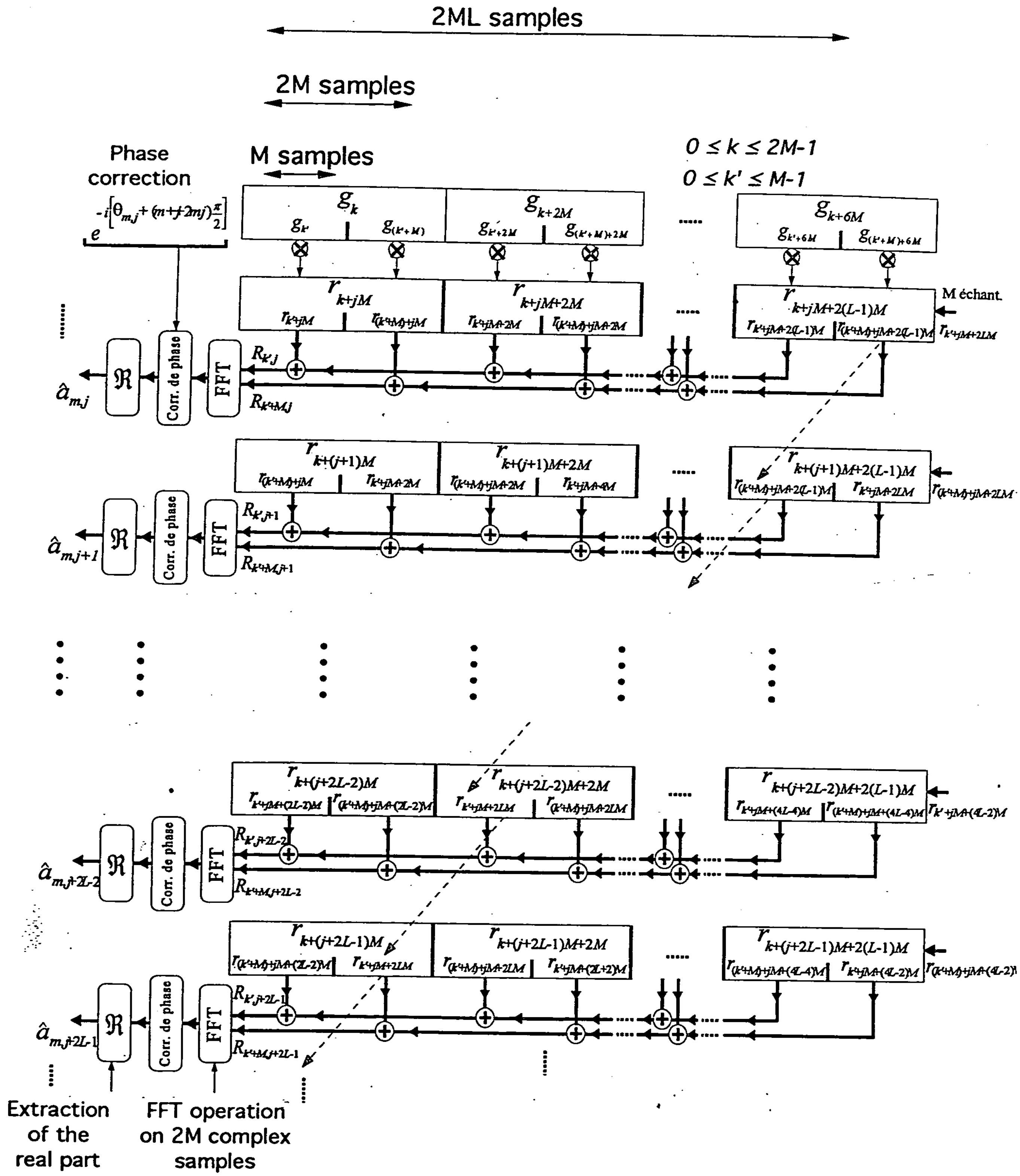


Fig. 7



2ML samples
85
2M samples
$0 \le k \le 2M-1$
$0 \le k' \le M-1$
M samples
Phase correction
$e^{-i\left[\theta_{m,j}+(m+j+2mj)\frac{\pi}{2}\right]}$
84
83
82
81
86
87
88
89
g_k
g_{k+2M}
g_{k+4M}
g_{k+6M}
M échant.
FFT
Corr. de phase
$\Re$
$R_{k',j}$
$R_{k'+M,j}$
$\hat{a}_{m,j}$
$\hat{a}_{m,j+1}$
$\hat{a}_{m,j+2}$
$\hat{a}_{m,j+3}$
$\hat{a}_{m,j+4}$
$\hat{a}_{m,j+5}$
$\hat{a}_{m,j+6}$
$\hat{a}_{m,j+7}$
r_{k+jM}
$r_{k+jM+2M}$
$r_{k+jM+4M}$
$r_{k+jM+6M}$
Extraction of the real part
FFT operation on 2M complex samples

Figure 8



2ML samples
2M samples
M samples
Phase correction
$0 \leq k \leq 2M-1$
$0 \leq k' \leq M-1$
M échant
Corr. de phase
FFT
Extraction of the real part
FFT operation on 2M complex samples

Fig. 9

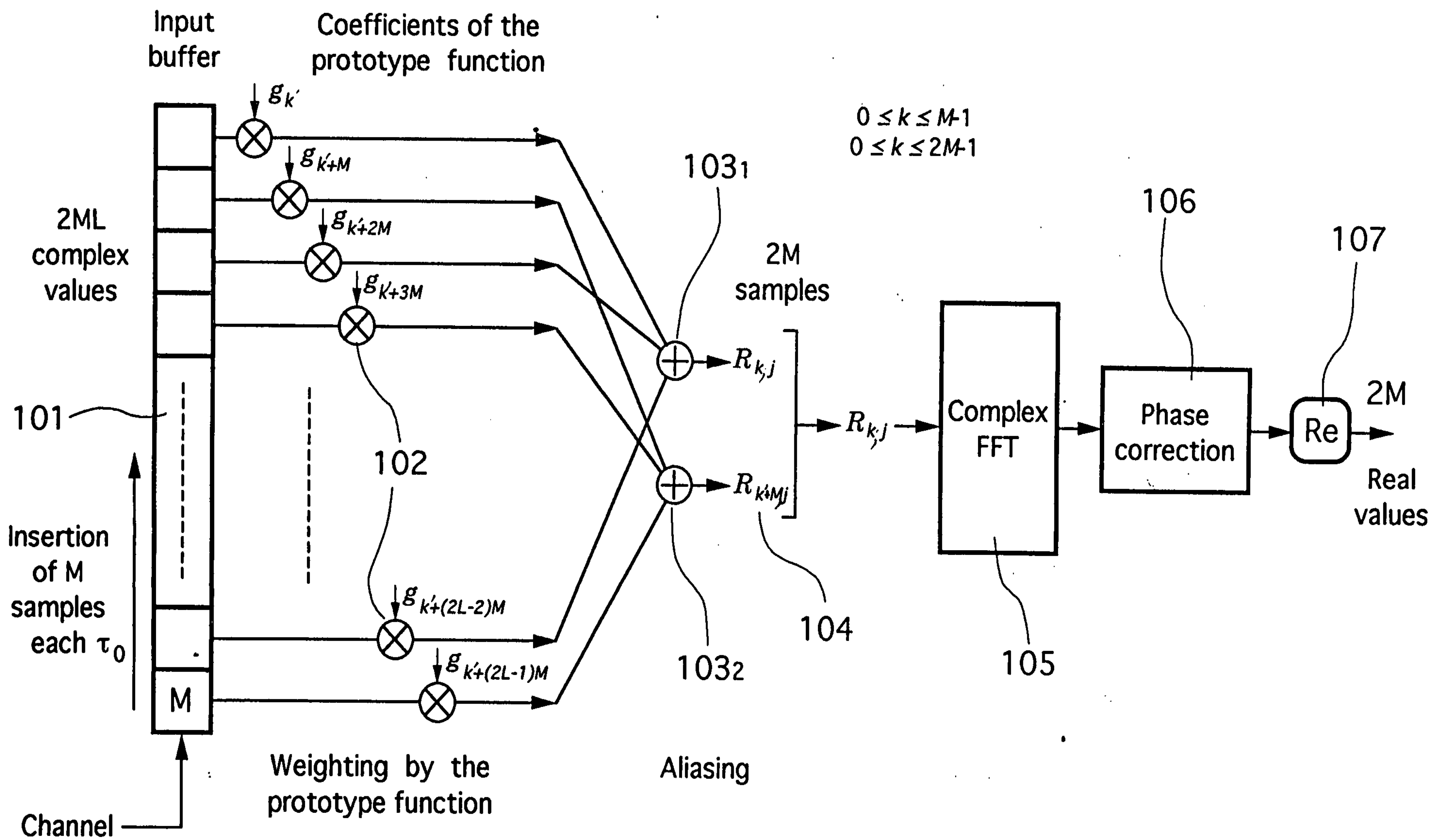

Input buffer
Coefficients of the prototype function
$g_{k'}$
$g_{k'+M}$
$g_{k'+2M}$
$g_{k'+3M}$
$g_{k'+(2L-2)M}$
$g_{k'+(2L-1)M}$
2ML complex values
101
102
M
Insertion of M samples each τ_0
Channel
Weighting by the prototype function
103_1
103_2
Aliasing
2M samples
$R_{k,j}$
$R_{k+M,j}$
104
$0 \le k \le M-1$
$0 \le k \le 2M-1$
$R_{k,j}$
Complex FFT
105
Phase correction
106
Re
107
2M
Real values

Fig. 10

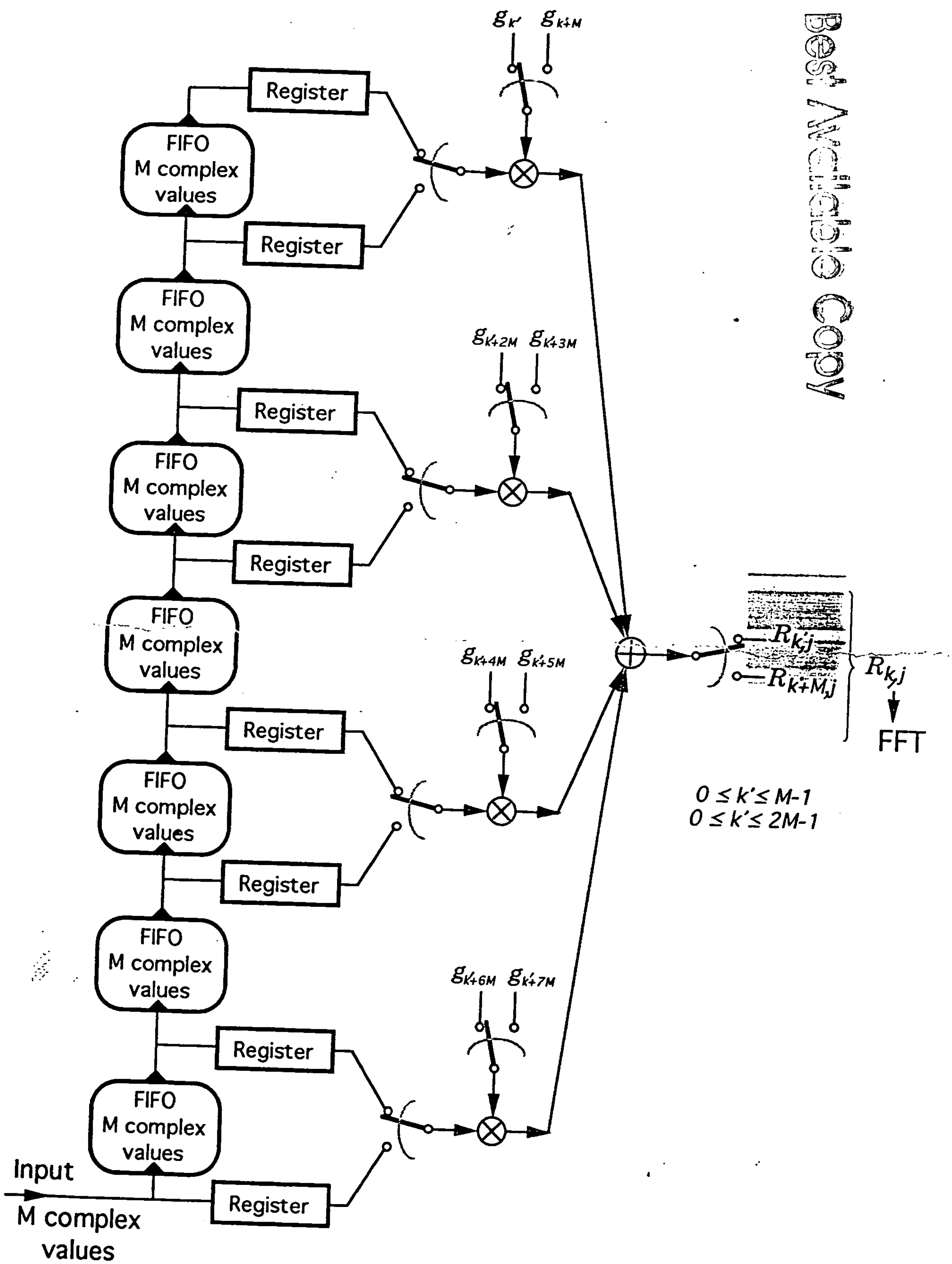

$g_{k'}$ $g_{k'+M}$
Register
FIFO
M complex
values
Register
FIFO
M complex
values
$g_{k'+2M}$ $g_{k'+3M}$
Register
FIFO
M complex
values
Register
FIFO
M complex
values
$g_{k'+4M}$ $g_{k'+5M}$
Register
FIFO
M complex
values
Register
FIFO
M complex
values
$g_{k'+6M}$ $g_{k'+7M}$
Register
FIFO
M complex
values
Input
M complex
values
Register
$R_{k',j}$
$R_{k'+M,j}$
$R_{k,j}$
FFT
$0 \leq k' \leq M-1$
$0 \leq k' \leq 2M-1$

Fig. 11

APPROVED BY DRAFTSMAN | O.G. FIG. | CLASS | SUBCL

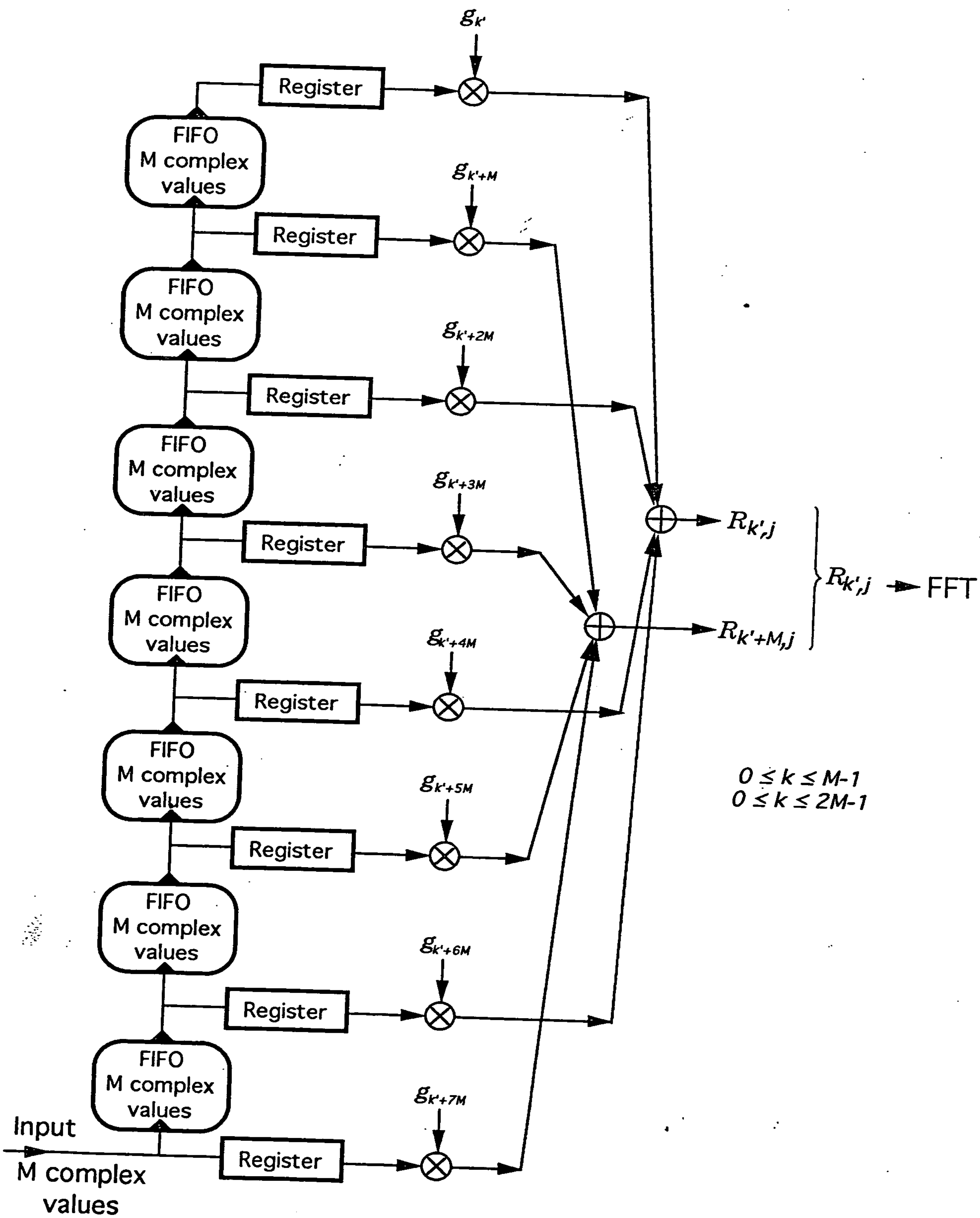


Fig. 12